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AFHRL-TR-90-83

AIR FORCE

HUMAN RESOURCES

AUTOMATIC INFORMATION PROCESSING AND HIGH-PERFORMANCE SKILLS: APPLICATIONS TO TRAINING, TRANSFER, AND RETENTION

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April 1991

Interim Technical Report for Period November 1989 – December 1990

LABORATORY

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235-5601

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
April 1991

3. REPORT TYPE AND DATES COVERED
Interim Report – November 1989 – December 1990

4. TITLE AND SUBTITLE
Automatic Information Processing and High-Performance Skills: Applications to Training, Transfer, and Retention

5. FUNDING NUMBERS
C – F33615-88 C-0015
PE – 62205F
PR – ILIR
TA – 40
WU – 01

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)
Logistics and Human Factors Division
Air Force Human Resources Laboratory
Wright-Patterson Air Force Base, Ohio 45433-6503

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFHRL-TR-90-83

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report documents a laboratory research effort which investigated automatic information processing theory and high-performance skills training. Training research issues pertaining to skill acquisition, transfer of training, or retention were investigated with analogs of Command and Control (C2) operator tasks in ten experiments. The results of the research indicate that elements of automatic processing theory are applicable to the training of C2 task analogs, suggest some limits on the transfer that can be expected under both aided and non-aided training conditions, and indicate that automatic processes associated with spatial pattern information show no significant decrement over 30-day retention intervals.

14. SUBJECT TERMS
automaticity
part-task training
skill acquisition
skill retention
skill transfer

15. NUMBER OF PAGES
202

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

SUMMARY

This document summarizes a 12-month research effort investigating automatic processing theory and high- performance skills training. Applied training research issues pertaining to skill acquisition, transfer of training, and retention were explored with analogs of Command and Control (C2) operator tasks. The results of this work indicate that elements of automatic processing theory can be applied to training of C2 task analogs, suggest some limits on the transfer that can be expected with complex materials under both aided and non-aided training conditions, and indicate that automatic processes associated with spatial pattern information show no significant decrement over 30-day retention intervals.

PREFACE

The work documented in this report was conducted under Air Force Human Resources Laboratory (AFHRL) Contract No. F33615-88-C-0015 with the University of Dayton Research Institute. This work supports an integrated research program which is developing advanced part-task training techniques based on information processing theory. Dr. Beverley A. Gable and Captain Michael T. Lawless served as the AFHRL/LRG, Wright-Patterson AFB, contract monitors.

We wish to thank Dr. David Biers and Mr. Ravi S. Adapathya for assistance with data analyses and Dr. Gregory Elvers for programming assistance. Ms. Kristie Holahan helped with data collection and report preparation, and Mr. Jeffrey Schmidt assisted in data collection.

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I. INTRODUCTION

Automatic Processing and High Performance Skills

Air Force Command and Control (C2) systems are capable of presenting large volumes of information that must be rapidly and accurately processed by system operators. These systems can impose multiple concurrent information processing demands on the operator, and therefore require highly skilled personnel capable of performing under high workload or timesharing conditions. The high-performance skills demanded of operators typically require extensive practice to develop and are characterized by qualitative differences between the novice and expert (Schneider, 1985).

The increases in speed, accuracy, and timesharing proficiency that can occur with extensive training have led to development of an automatic/controlled theory of information processing (Logan, 1985; Schneider, Dumais, & Shiffrin, 1984; Shiffrin & Schneider, 1977). This theory distinguishes two qualitatively different forms of information processing: automatic and controlled.

Within the automatic/controlled processing framework, automatic processing represents a rapid, parallel, and effortless process not subject to the capacity or resource limits usually associated with performance. Controlled processing, on the other hand, is characterized as a relatively slow, effortful, and sequential process that is resource/capacity limited. Automatic processing develops with extended practice under consistently mapped (CM) conditions in which there is a consistent relationship between task components (e.g., a stimulus and the required response). Controlled processing is typically associated

either with novel tasks or with variably mapped (VM) conditions in which task component relationships vary from situation to situation.

According to this theory, automatic processes can represent important components of skilled operator performance. Certain elements of skill result from automatization of CM task components, which contributes to the speed and efficiency of expert performance. Most skilled performance is, however, conceptualized as the product of both controlled and automatic processing (Logan, 1985; Schneider et al., 1984; Shiffrin & Dumais, 1981).

Because of the efficiency that characterizes automatic processing, such processes are of potential importance to Air Force C2 operator performance. As noted above, automatic tasks are performed more rapidly than controlled tasks (e.g., Eggemeier, Granitz, Rogus, & Geiselman, 1990; Fisk, Hodge, Lee, & Rogers, 1990; Fisk & Schneider, 1983; Hale & Eggemeier, 1990). Automatic processes can also result in more accurate (e.g., Myers & Fisk, 1987; Shiffrin & Schneider, 1977) and less variable (e.g., Myers & Fisk, 1987) performance than controlled processes.

In addition to speed and accuracy advantages associated with automatic processes, an important potential benefit of such processing within the context of C2 systems operation is improved operator timesharing efficiency. Improvement in timesharing efficiency is particularly important due to the high workload that can be imposed by some C2 systems, and results from the reductions in the capacity/resource expenditure associated with the processing of CM components. If the processing requirements of a CM task component were reduced through automatic processing, the resulting additional capacity could be applied to other tasks or components, thereby improving timesharing efficiency. The expected increases in timesharing efficiency have been demonstrated in a number of experiments where automatized tasks

have been performed at high levels with concurrent controlled tasks (e.g., Fisk & Schneider, 1983; Schneider & Fisk, 1982, 1984).

Implications of Automatic/Processing Theory for Training

The distinction between CM and VM task elements has some important implications for the structure of training programs intended to support the development of automatic processing. Because only CM task components can be automatized, the theory suggests that training programs should be structured to permit numerous repetitions of these task components. Also, because extensive practice is typically required to establish automatic processing in appropriate task components, part-task training of CM components appears to represent a viable and cost-effective means of providing the required training. In essence, this approach to establishing automatic processing in selected task components requires that CM elements of operator tasks be identified through task analytic or other techniques, and that the CM component identified through these analyses be implemented on part-task trainers to provide the requisite training. Once evidence of automatic processing has been established, the CM task components would have to be integrated into the total task through full simulation or other whole task training techniques.

Application of the automatic-processing-based approach to C2 operator skill acquisition does, however, require extensions of current laboratory work in several important areas. Three such areas include (a) more extensive specification of the range of task materials and conditions which permit development of automatic processes; (b) further investigation of the transfer that can be expected with automatic processes for such materials and conditions; and (c) specification of the retention functions associated with automatic processes for the types of materials processed by operators of C2 systems.

Specification of the range of task materials and conditions that permit the development of automatic processing is important from the perspective of determining whether major classes of C2 operator task subcomponents represent candidates for automatic processing. As described in greater detail below, for example, operators of certain C2 systems must rapidly and accurately process complex alphanumeric rules that represent combinations of letter sequences or acronyms which stand for particular system parameters and numerical values associated with such parameters. These C2 systems require that the operator search a display and respond to critical or target alphanumeric sequences representing parameters that are out of tolerance. At the same time, responses must be withheld from non-critical or distractor sequences that represent parameters within tolerance.

Although considerable previous work has addressed automatic processing in search paradigms that require a distinction to be drawn between target and distractor items, this research has not addressed the issue of automatization of complex alphanumeric rules which require the conjunction of acronyms and numerical values. Therefore, it is important to investigate the effects of extensive training on such complex alphanumeric rules (a) to determine if they can develop characteristics of automatic processing and (b) to specify the amounts of training that would be required for developing such characteristics.

A related area important to application of an automatic-processing-based approach to the types of materials represented in C2 systems is investigation of techniques that can be applied to facilitate the development of automatic processing with complex materials. This area is important from a practical perspective, because automatic processing typically requires extensive training and can take thousands of acquisition trials to develop. Any techniques that could shorten the amount of training time required to establish some level of automatic

processing with complex materials would therefore be of great potential benefit to applications to C2 operator training.

In addition to information pertaining to the conditions and materials that permit the development of automatic processing in subcomponents of operator tasks, additional data bearing on the transfer of automatic subcomponents of operator tasks are needed to effectively structure training programs. Such data are necessary, for example, to determine if limited subsets of relevant materials can be trained and then used as a basis for subsequent formal or on-the-job training with other similar materials.

Other issues that pertain to transfer concern possible task recombinations in which originally trained target items, distractor items, or both are incorporated into a new overall task. Such a task could require that items serve either the same target/distractor roles or different roles, and it is necessary to determine the levels of performance which result from different task recombinations. Previous work with semantic-based and symbolic materials (e.g., Dumais, 1979; Fisk et al., 1990) suggests that positive transfer would occur when target items are incorporated into a task with new distractor items, and that similar positive transfer could be expected with distractor transfer. It is important, however, to extend this previous transfer work to tasks that are representative of other subcomponents (e.g., spatial pattern search) of C2 operator tasks.

A third major area relevant to the application of automatic-processing-based approaches to part-task training of C2 operator tasks concerns the retention of automatic processes. Specification of retention functions for such processes is necessary to permit effective structuring of training programs designed to maintain subcomponent skills over time periods during which these skills may not be exercised. It would be possible,

for example, for an air weapons controller to experience a time period when certain types of air refueling missions were not run and particular subcomponent skills associated with such missions were not practiced. However, when these air refueling missions were resumed, it would be very important for controller skill levels to be within acceptable margins to ensure the safety of the missions. Knowledge of the retention functions associated with the subcomponents of the skills would be essential in such an instance to determine if retraining would be required during the period of disuse. Previous work with the retention of automatic processing with semantic materials (Fisk et al., 1990) indicates that automatic processes undergo little or no loss over 6-month periods. Once again, however, it is important to extend this previous work to other materials designed to represent analogs of information found in C2 operator task components.

Objectives of Current Research Program

The current research program was therefore designed to investigate applications of an automatic-processing-based approach to the acquisition, transfer, and retention of tasks intended to represent the types of information-processing requirements imposed by selected task components within C2 systems. The purpose of this report is to document a series of experiments conducted to examine issues concerned with the acquisition, transfer, and retention of automatic processing in laboratory analogs of C2 task components.

Section II of this report presents a series of experiments conducted to examine the acquisition of automatic processing in several tasks involving the processing of information similar to that required of operators of C2 systems. Section III reports a number of experiments that examined the issues of transfer and retention of automatic processing in analogs of C2 operator tasks. Finally, Section IV describes a set of experiments performed to initially evaluate the feasibility of a target

prompting system intended to facilitate the development of automatic processing in a complex spatial pattern detection task.

II. ACQUISITION OF AUTOMATIC PROCESSES IN TASKS REQUIRING THE PROCESSING OF SPATIAL PATTERN INFORMATION AND ALPHANUMERIC RULE-BASED INFORMATION

Air Force C2 systems such as air weapons control and event detection require the operator to rapidly and accurately process a variety of spatial and complex alphanumeric information under high workload conditions (Eggemeier, Fisk, Robbins, Lawless, & Spaeth, 1988). This information is different in both type and complexity from the relatively simple alphanumeric materials (e.g., individual numerals or letters of the alphabet) employed in many earlier laboratory studies of automatic processing (see Schneider et al., 1984 for a review). As a consequence, information from these earlier studies may not be directly applicable to the training of operator task components that require the use of spatial and complex alphanumeric materials.

The objective of the experiments described in this section was to investigate the development of automatic processing in memory and visual search tasks requiring the processing of information analogous to that required in Air Force C2 systems.

Spatial Pattern Information

The first set of experiments in this series addressed the issue of automatic processing of spatial pattern information. As noted above, Air Force C2 systems such as air weapons control and event detection require the operator to process different types of spatial pattern information. These spatial patterns portray the presence and movement of certain items (e.g., aircraft) on systems displays (Eggemeier et al., 1988). System displays within air weapons control systems, for example, require the operator to monitor the radar returns associated with aircraft that are

controlled, and to detect changes in the speed or direction of aircraft movement through associated changes in the spatial patterns of radar returns on the system display. One important characteristic of controlled aircraft is acceleration, and this variable is portrayed by progressive increases in the distance between successive returns on the display. Changes in course, on the other hand, are depicted by changes in the direction of movement of successive returns on the display. Although spatial pattern information is essential to operator performance within such systems, relatively little work has investigated automatic processing of such information.

Work conducted to date with automatic processing of spatial pattern information (e.g., Eberts & Schneider, 1986; Eggemeier et al., 1990; Lawless & Eggemeier, 1990) has produced somewhat mixed results regarding the capability of subjects to automatize such information. Eberts and Schneider (1986), for instance, reported several studies of the effect of extensive practice on the detection of line segment patterns made up of individual elements presented sequentially on several channels of a visual display. Both CM and VM conditions were included in the experiments, and the results demonstrated a number of advantages of CM training that were consistent with the development of some degree of automaticity in that condition. For example, CM targets were detected more reliably than were VM targets, and maintained that advantage when the number of channels to be monitored was increased. CM performance was, however, affected by the number of channels to be processed, and this led Eberts and Schneider (1986) to suggest that only a partial form of automatic processing had been achieved in the CM condition.

Eggemeier et al. (1990) investigated the effect of extensive practice on performance in a memory search task that required the processing of static spatial patterns intended to represent classes of target movement that are processed by operators of C2 systems. All pattern elements were presented in parallel as

opposed to the sequential presentation of elements used in the Eberts and Schneider work. Both CM and VM mapping conditions were examined. At the conclusion of training, CM performance was more rapid than VM performance. The CM group also showed the attenuation of memory set size effects on reaction time performance that is indicative of automatic processing. Results of the Eggemeier et al. (1990) work therefore support the capability of subjects to develop automatic processing with static spatial pattern information.

In an initial investigation of the application of automatic processing to dynamic spatial patterns of the type processed by C2 operators, Lawless and Eggemeier (1990) examined performance with a weather pattern detection task that required subjects to search a display for complex spatial patterns that exhibited apparent motion characteristics. Elements of these patterns were also displayed sequentially. However, unlike the Eberts and Schneider (1986) pattern elements, each element remained on the display once it had initially appeared. Subjects completed 12 days of training under either CM or VM training conditions. Results of the Lawless and Eggemeier (1990) study showed that although the CM training group demonstrated a consistent advantage over the VM group in the search time required to detect target weather patterns, this advantage was not statistically reliable.

The results of current work on the development of automatic processing with spatial pattern information therefore provide evidence of automatic processing with static spatial patterns under memory search conditions. However, research using dynamic patterns that exhibit apparent movement and/or that include sequentially presented elements has produced results that are consistent with either partial automaticity or non-significant CM performance advantages. Additional work to explore the boundary conditions for establishment of automatic processing with both static and dynamic spatial patterns is therefore important for

eventual applications of an automatic-processing-based approach to C2 operator training.

Complex Alphanumeric Information

An additional important application of automaticity for high-performance skills training concerns the processing of complex alphanumeric information. In some instances, operators of Air Force C2 systems (e.g., event detection, air weapons control) must search a display for alphanumeric characters (e.g., acronyms representing system parameters or aircraft), and automatic processing of this type of information is an important aspect of performance in these systems.

As outlined previously, for instance, certain Air Force C2 systems require the operator to process complex alphanumeric information. This information takes the form of the conjunction of sequences of letters of the alphabet that stand for particular systems parameters, and numerical values associated with the status of that particular parameter. In these systems, an operator can be required to search a display that contains a number of parameter designators and associated numerical values, and rapidly determine whether the numerical values associated with each parameter fall within pre-specified boundaries. In effect, this represents a rule-based search task in which a rule is defined by the conjunction of a system designator and a range of numerical values, and the search set consists of the combination of the system designator and a numerical value that represents either an exemplar or a non-exemplar of the rule.

This type of rule-based search task is conceptually similar to a semantic category search task that has developed characteristics of automatic processing with extensive practice in a number of previous efforts (e.g., Fisk et al., 1990; Fisk & Schneider, 1983; Hale & Eggemeier, 1990; Hassoun & Eggemeier, 1988; Schneider & Fisk, 1984). Hale and Eggemeier (1990), for

example, demonstrated the development of automatic processing in a memory search variant of this type of task that required subjects to determine whether single probe items (e.g., automobile, potato) represented exemplars of previously presented semantic categories (e.g., mode of transportation, vegetable) that made up the memory set. Extensive training was provided to subjects under both CM and VM conditions. The results demonstrated that performance in the CM condition was more rapid than comparable VM performance, and also showed that the effects of memory set size on performance were attenuated in the CM condition relative to the VM condition. These results were consistent with the development of automatic processing in the CM condition, and other investigators (Fisk et al., 1990; Fisk & Schneider, 1983; Hassoun & Eggemeier, 1988; Schneider & Fisk, 1984) have reported similar evidence that supports the development of automatic processing in this type of paradigm.

Certain parallels exist between the semantic category search paradigm described above and the rule-based search task performed by C2 operators. In both instances, a general category or rule defines the characteristics or boundaries of the search set, and in both cases, successful performance of the task requires that single items be classified as exemplars or non-exemplars of the category or rule. However, the semantic category search paradigm employs information categories used extensively prior to their application in the search task, whereas the rule-based search task requires the conjunction of system designator and numerical values not previously associated with one another.

Previous work (Eggemeier et al., 1990) has confirmed the capability of subjects to automatize letter sequences similar to those used as system component designators in C2 systems, and several investigators (e.g, Fisk, Oransky, & Skedsvold, 1988; Kramer, Strayer, & Buckley, 1989) have recently demonstrated application of rule-based consistencies to the development of automatic processing. There have been, however, no previous

investigations of the capability of subjects to develop automatic processing in a rule-based search task involving the conjunction of alphanumeric characters required of the C2 operator. Therefore, the effects of practice on the capability to perform this complex type of search task represent an important issue in the application of automatic-processing-based approaches to C2 operator training.

Overview of Present Studies

Results of some recent research with spatial and complex alphanumeric materials suggest that characteristics of automaticity identified with more basic materials can, in fact, apply to subsets of materials that are more representative of those which must be processed by operators of C2 systems. Some results do, however, suggest that important limits may exist on the degree of automaticity that can be achieved under certain situations. The Eberts and Schneider (1986) research, for example, raises important issues regarding the degree of automaticity that can be developed when target patterns are spatial in nature or when such patterns are composed of sequentially presented elements. Likewise, the Lawless and Eggemeier (1990) work with dynamic spatial patterns in a complex search task suggests that there may be some limits on the application of automatic processing to such situations. The capability to achieve only partial forms of automaticity or to realize only limited advantages of CM training under such conditions is of great potential importance in applications to Air Force C2 systems, as these systems would typically impose similar conditions on operator performance.

In the same vein, although previous work suggests that complex alphanumeric materials of the type represented in the rule-based type of search task discussed above can be automatized, present data do not extend to the rule-based application itself. Once again, there is a need to extend current

information to an application that more closely approximates C2 system requirements.

One major objective of the current effort was to investigate the development of automatic processing in tasks which impose processing requirements similar to those involved in Air Force C2 systems. Given the importance of spatial pattern and complex alphanumeric information to such systems and the relatively little automatic processing work conducted with these types of information, additional investigations were required to examine the development of automatic processing in these areas.

Therefore, the following experiments were performed to investigate levels of performance that could be achieved with extended training in tasks requiring the processing of spatial pattern information and complex alphanumeric information. Experiment 1 examined the effects of training on a task which required that subjects search for static spatial patterns representative of those which must be processed in several Air Force systems. Experiments 2 and 3 investigated the effects of training under CM and VM conditions on performance with dynamic spatial pattern information of the type included in C2 systems in visual and memory search tasks, respectively. Finally, Experiment 4 examined the effects of CM and VM training on performance of a rule-based alphanumeric search task of the type described above.

Experiment 1
Development of Automatic Processing in a Static Spatial Pattern Search Task

Purpose

The purpose of this experiment was to investigate the levels of performance which could be achieved in both CM and VM conditions in a memory search task that required the processing of static spatial pattern information. The memory search task was chosen for this work because it requires that a number of target patterns be held in memory and that a subsequently presented test pattern be rapidly and accurately classified as a member or non-member of the set. Target patterns require a rapid positive response, whereas non-target or distractor patterns require a negative response. Because it requires one type of response to a target subset and another type of response to a non-target subset, this type of memory search is associated with important operator functions in several C2 systems, such as event detection. During the event detection function, an operator is required to respond positively to the occurrence of a subset of target events, and to respond in a different manner to non-target or distractor events. Because of its similarity to a component of important operator functions in C2 systems, the memory search task was considered ideal to investigate the capability of subjects to achieve some degree of automatic processing with static spatial pattern information.

As noted above, Eggemeier et al. (1990) have reported evidence of the development of automatic processing with static spatial patterns intended to represent different classes of target movement within Air Force C2 systems. These systems require the operator to identify spatial patterns associated with the movement of targets or events (e.g., aircraft, weather phenomena) represented by dot patterns which progressively move across the system display with elapsed time. Three principal patterns of movement are typical with such targets or events: (a)

constant movement represented by equal spacing between pattern elements, (b) accelerated movement represented by progressive increases in the spacing between pattern elements, and (c) decelerated movement represented by progressive decreases in the spacing between pattern elements.

To represent these major categories of target movement, Eggemeier et al. (1990) developed three sets of static spatial pattern stimuli. One set of stimuli was designed to represent constant target movement, the second set was designed to represent accelerated target movement, and the third set was designed to represent decelerated target movement.

In the Eggemeier et al. (1990) study, target and distractor patterns were chosen from separate movement categories as defined above. For example, target items for one subject were chosen from the constant movement category, whereas distractor items were chosen from the accelerated target movement category. The use of movement categories as targets and distractor sets was counterbalanced across subjects. In effect, the use of separate categories of target and distractor items provided the opportunity for subjects to attend to the one common feature of the spatial patterns in the target set, and to do the same with distractor set patterns. Therefore, although the development of automatic processing was demonstrated with the spatial pattern materials used, it is possible that the categorization present in the target and distractor sets contributed to the capability of subjects to automatize the spatial pattern sets.

Eggemeier et al. (1990), for example, have demonstrated that similarity between target and distractor set items is an important factor in the development of automatic processing with complex alphanumeric materials. Under equivalent levels of training, for instance, dissimilar target and distractor sets led to faster performance and greater attenuation of memory set size effects than did similar target and distractor sets. The

dissimilarity between target and distractor sets in the Eggemeier et al. (1990) spatial pattern experiment could have therefore facilitated the achievement of the performance levels obtained.

Because such dissimilarity between target and distractor sets cannot be guaranteed in C2 systems, it was considered important to investigate the development of automatic processing with spatial pattern information when target and distractor items were not drawn from separate categories. Therefore, Experiment 1 was conducted to investigate the development of automatic processing in static spatial patterns similar to those required by some Air Force systems, but which did not include the categorization between target and distractor sets that had been present in the earlier work. To eliminate the categorization, new sets of target and distractor items were developed through random selection of patterns from the three categories of spatial patterns used in the Eggemeier et al. (1990) experiment.

Method

Subjects. Subjects were 12 University of Dayton students, paid $4.00 per hour for their participation. In addition to this base rate of pay, subjects were awarded a bonus payment of $1.00 per hour for appearing on time for each scheduled experimental session.

Apparatus. The experiment was controlled with a Zenith Data Systems 248 computer. The computer was programmed to present stimuli, control the timing of stimulus presentation, and collect subject responses. Subjects viewed spatial pattern stimuli on a Zenith ZCM-1490 high-resolution color monitor. Responses were made on the arrow keys located in the lower right-hand corner of a standard expanded IBM-compatible keyboard. Auditory feedback concerning performance levels was presented to subjects through the speakers on the Zenith computers.

Procedure. Subjects performed a memory search task which was modeled after the Sternberg (1966) paradigm. On each trial, subjects were shown a memory set of one to four spatial patterns on the computer cathode-ray tube (CRT) screen. These spatial patterns remained on the screen until the subject pressed a designated key on a computer keyboard. At this point, a fixation cross 4.5 millimeters (mm) in height and 4.3 mm in width appeared in the middle of the screen for 500 milliseconds (ms). The fixation cross was replaced by a single test pattern displayed for a maximum of 2 seconds or until the subject responded.

The subject was instructed to rapidly determine whether the test pattern was a member of the previously presented memory set. Subjects responded "yes" or "no" by pressing with their preferred hand a labeled response button on the keyboard. One-half of the target patterns in each block of trials were members of the memory set; the other patterns were not. Two dependent measures, reaction time and response accuracy, were collected. Each subject was encouraged to respond as rapidly as possible while maintaining an accuracy level of 90% or higher within each session.

Visual and auditory feedback were provided to subjects at the completion of each trial. After each trial, an incorrect response was followed by a "Wrong Response" message on a red background, and by a tone. A correct response was followed by a "Correct Response" message on a blue background, the reaction time for that trial, and a short musical sequence for those reaction times that were below a specified criterion. In addition, the feedback concerning correct responses also included a message specifying the level of performance indicated by the reaction time achieved. This feedback indicated to the subject if the level was that of a "Novice," "Professional," "Expert," or "Ace." These levels represented progressive decreases in reaction time to the spatial pattern information, and the feedback encouraged the subject to attempt to lower reaction time if only

the "Novice" level had been achieved on a particular trial. Performance categories were based on reaction times achieved by subjects in a pilot study which preceded the present experiment.

Additional summary feedback was provided at the beginning of each day of training following the initial training day. This feedback summarized reaction time and accuracy performance levels from each of the previous training days, and provided a means for subjects to follow changes in their performance as a function of training.

Subjects participated in the experiment for 10 days. On each day, subjects completed two 30-minute training sessions which consisted of 10 blocks of 20 trials each. Therefore, there were 400 training trials each day and a total of 4,000 training trials across the experiment.

Stimulus Materials. Each spatial stimulus pattern was composed of five circular elements, and was intended to represent the type of pattern processed by operators of some Air Force C2 systems. Six different target/distractor sets were developed through a random selection procedure from the categorized sets of patterns used in the Eggemeier et al. (1990) research. The current procedure therefore permitted the use of the same patterns as in the previous work, and at the same time, eliminated the categorization present in the previous stimulus sets. Each set of patterns in the current experiment included four targets and four distractor patterns. Examples of the patterns used are provided in Appendix A.

Design. Three independent variables were included in the design: (a) target/distractor mapping, (b) memory set size, and (c) training sessions. Target/distractor mapping was either CM or VM, and represented a between-subjects variable. Six subjects were assigned to the CM group and six subjects to the VM group. In the CM condition, one set of spatial patterns served as

targets throughout training for an individual subject, and a second set served as distractor patterns. In the VM condition, sets of patterns served as both targets and distractors across blocks of trials. The six sets of spatial pattern stimuli were distributed across subjects in both the CM and VM conditions. Under CM conditions, four items of a set served as targets and the remaining four items served as distractors. In VM conditions, targets and distractors were drawn at random on a trial-by-trial basis from the total set of eight items included in a pattern set. Each pattern set served as targets/distractors for one CM subject and for one VM subject. Memory set size was manipulated within blocks of trials in each group, and consisted of one to four spatial patterns. Each group completed 20 sessions of practice trials across the 10 days of training.

Results

Reaction Time. Mean reaction time to test patterns as a function of CM/VM condition and training sessions is illustrated in Figure 1. The means depicted in Figure 1 are based on correct responses by subjects. As is clear from the figure, both CM/VM condition and sessions had a substantial effect on reaction time. Reaction times were consistently lower in the CM group than in the VM group, and also improved in both groups as a function of training.

A 2-x-4-x-20 Analysis of Variance (ANOVA) was performed on the reaction time data to analyze the effects of mapping condition (CM vs. VM), memory set size (1-4), and training session (1-20). Mapping condition was a between-subjects variable in this analysis, while memory set size and training session were within-subjects variables. This analysis indicated that the main effects of mapping condition [$F(1,10) = 10.58$, $p < .01$], memory set size [$F(3,30) = 150.56$, $p < .001$], and training sessions [$F(19,190) = 35.91$, $p < .001$] were significant. The interactions

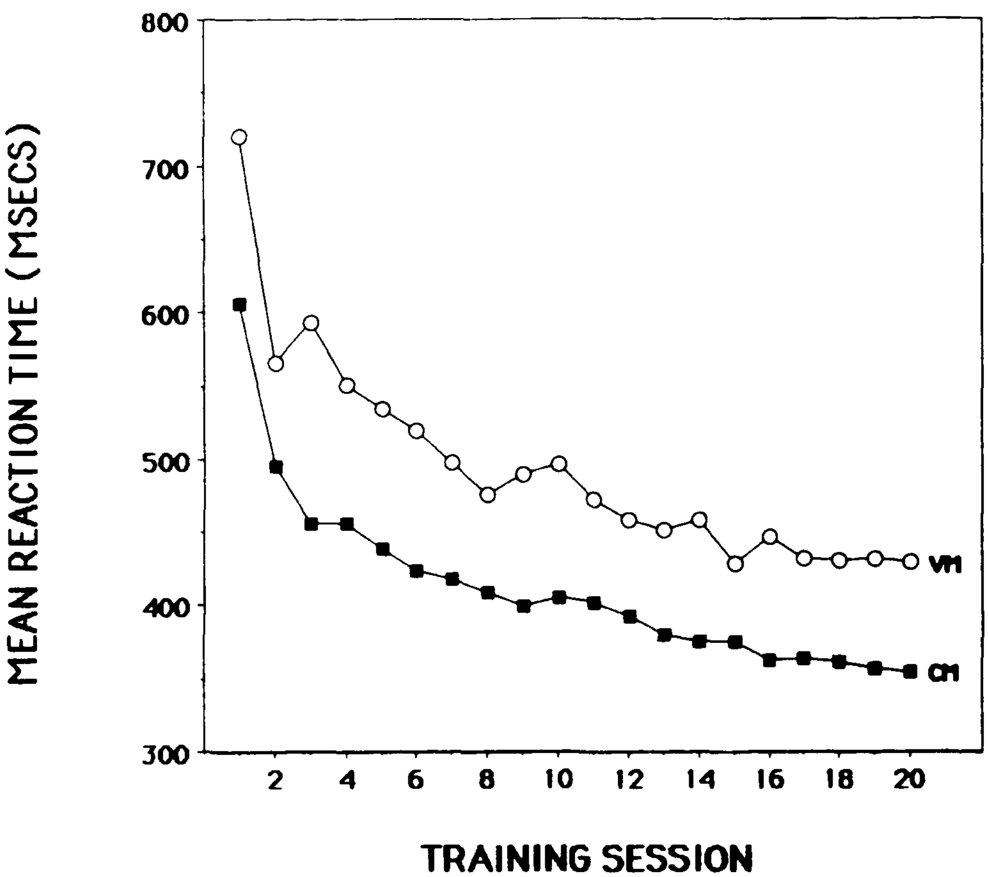

Figure 1. Mean Reaction Time as a Function of Mapping Condition and Training Session.

of CM/VM x memory set [$F(3,30) = 13.26$, $p < .001$] and memory set x session [$F(57,570) = 4.92$, $p < .001$] were also significant. Neither the CM/VM x session nor the CM/VM x memory set x session interaction proved significant.

The main effect of CM/VM mapping condition is consistent with the development of some degree of automatic processing in the CM condition, in that reliably faster responses were exhibited in the CM condition as compared with the VM condition. The significant improvement in performance with training and the effect of memory set size on reaction time are consistent with previous work (e.g., Fisk & Schneider, 1983) with the same memory search paradigm with different materials. Therefore, the main effects are consistent with expectations and with the development of automatic processing in the CM group.

As noted above, one criterion used in assessing the development of automatic processing is the response time advantage of the CM group over the VM group. A second criterion which can be applied to test the development of automatic processing is a greater reduction in the effect of task demand within the CM group versus the VM group as training progresses. Within the current memory search task, task demand was varied through manipulations of memory set size. Therefore, a reduction in the effect of memory set size in the CM versus the VM group with training represents a second criterion that can be applied in the present study to assess the development of automatic processing with the present spatial patterns. The significant CM/VM x memory set interaction reported above is consistent with the presence of a differential effect of memory set size within the CM and VM groups.

Figure 2 shows the effect of memory set size on reaction time in the CM and VM groups for both the first and last sessions of training. As is clear from the figure,

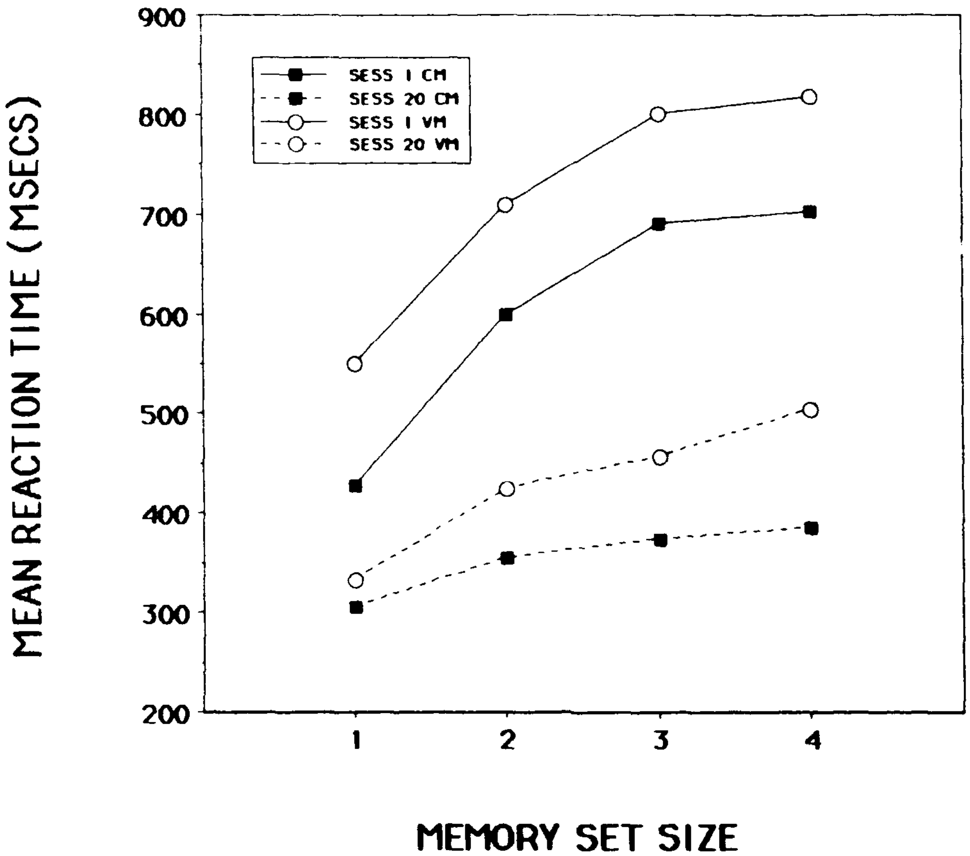

Figure 2. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Training Session.

memory set size had a substantial effect on both CM and VM performance during the first training session. Subsequent to the significant CM/VM x memory set interaction, tests of simple main effects of memory set on performance within the CM group and within the VM group were performed on Session 1 data to evaluate the influence of memory set on reaction time at the beginning of training. This analysis indicated that the effect of memory set was reliable within both the CM [$F(3,30) = 40.25$, $p < .001$] and VM [$F(3,30) = 37.38$, $p < .001$] conditions. A Tukey-A (Winer, 1962) post-hoc multiple comparison test indicated that within the CM group, the reaction times associated with memory set size one differed reliably ($p < .05$) from all other memory set sizes, and that reaction times for the memory set size of two patterns differed significantly from those associated with memory set sizes of three and four patterns. Exactly the same pattern of results was obtained in an application of the Tukey-A procedure to the Session 1 VM group data. Therefore, memory set size exerted very similar effects on reaction time performance at the beginning of training in both the CM and VM groups.

At the conclusion of training, however, the effect of memory set on reaction time had been markedly attenuated in the CM group, while set size continued to show a strong effect on VM group performance. Tests of simple effects of memory set on the Session 20 VM group data showed a reliable effect of memory set on reaction time [$F(3,30) = 39.45$, $p < .001$] that was of approximately the same magnitude as the Session 1 effect. A comparable CM analysis continued to demonstrate a reliable effect memory set on Session 20 reaction time [$F(3,30) = 9.55$, $p < .001$], but the magnitude of the effect was greatly reduced relative to the Session 1 effect. Tukey-A multiple comparison tests confirmed these trends, and indicated that only the reaction times for the memory set size of one differed from the remaining reaction times in the CM condition. Within the VM condition, on the other hand, reaction times of memory set size one differed from all other reaction times, as did those associated with memory set size

four. These results demonstrate that at the completion of training, the CM group showed a marked attenuation of memory set size effects at the higher memory set sizes, while the VM group continued to show a reliable effect of the highest memory set size on reaction time. This type of effect is consistent with the development of automatic processing within the CM group.

To further characterize the reductions in memory set size on performance in each group, slopes of the functions depicted in Figure 2 were computed. Within the CM group, the slope of the Session 1 function was 92 ms, and the slope of the Session 20 function was 26 ms. In the VM group, however, the slope of the Session 1 function was 90 ms, and was reduced to 54 ms by Session 20. Therefore, the CM group showed a 72% reduction in slope with training as compared to a 40% reduction in slope in the VM group. Once again, this type of CM-VM difference is consistent with the development of automatic processing in the CM group.

Accuracy of Responding. Figure 3 shows mean percent correct responses as a function of CM/VM group and training session. As can be seen in the figure, response accuracy was consistently high, and generally improved in both groups as a function of training.

A 2-x-4-x-20 ANOVA comparable to that performed on the reaction time data was conducted on the percent correct responses. This analysis demonstrated no main effect of mapping condition [$F(1,10) = 4.13$, $p > .06$], a significant main effect of memory set size [$F(3,30) = 24.09$, $p < .001$], and a reliable effect of training sessions [$F(19,190) = 5.46$, $p < .001$]. The CM/VM x memory set interaction [$F(3,30) = 7.49$, $p < .002$] was reliable, but all other interactions proved non-significant. The main effect of memory set size reflects increased error rates in both groups as memory set size increased, and the main effect of training session reflects the trend for increased accuracy in both mapping groups over the initial training sessions as noted

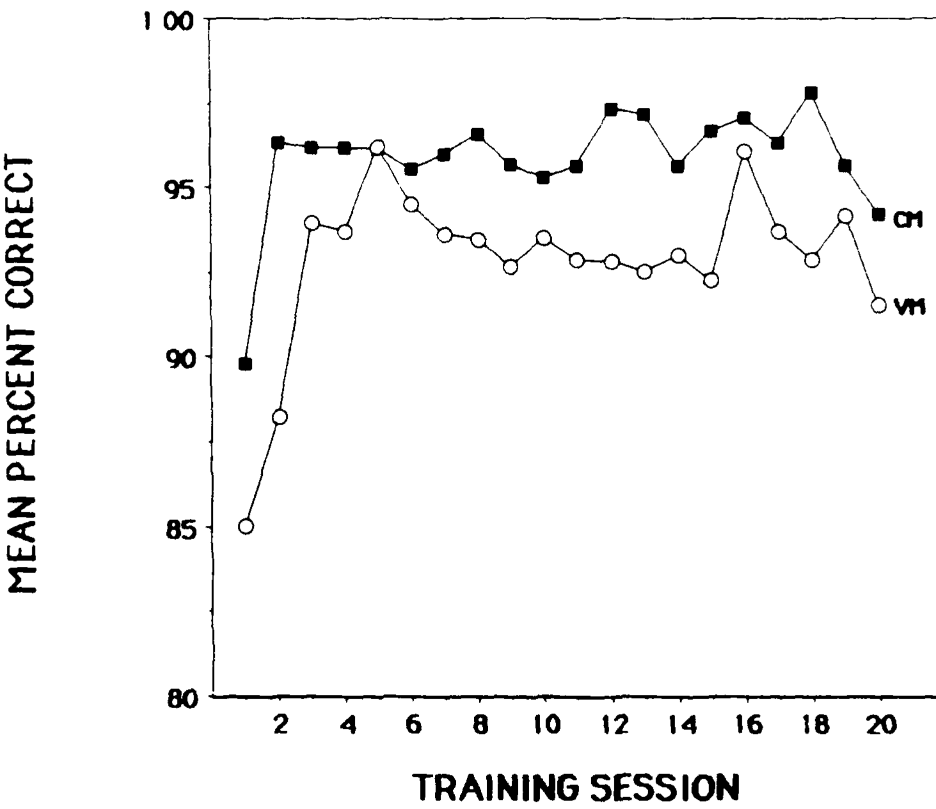

Figure 3. Mean Percent Correct as a Function of Mapping Condition and Training Session.

in Figure 3. Although the CM-VM main effect was not reliable, it did approach significance. Figure 3 demonstrates a clear trend for higher levels of accuracy in the CM versus the VM condition across training. Consequently, the difference in reaction times noted in Figure 1 cannot be attributed to a significant speed-accuracy tradeoff, and the accuracy data are therefore consistent with the interpretation of reaction time differences as supporting the development of automatic processing in the CM group.

Figure 4 shows the effect of memory set on percent correct as a function of mapping condition during Session 1 and during Session 20. As is clear from the figure, CM performance was generally superior to VM performance during Session 1, and the percent correct in both groups tended to decrease as memory set size increased. The same trend for superiority of CM relative to VM performance is clear in Session 20, although both groups show more stable performance at the higher memory set sizes than in Session 1.

Tests of simple effects comparable to those performed on the reaction time data were conducted following the significant CM/VM x memory set interaction. These analyses indicated that within Session 1, memory set reliably affected VM performance accuracy [$F(3,30) = 3.07$, $p < .05$], but not CM performance accuracy [$F(3,30) = 1.60$, $p > .05$]. A Tukey-A post-hoc comparison test indicated that within the VM condition, the memory set size of four patterns was associated with a lower percent correct than was the memory set size of one pattern ($p < .05$), but that all other differences were not reliable. Comparable tests of simple main effects on the Session 20 data indicated that there were no significant differences associated with memory set in either the CM [$F(3,30) = 2.00$, $p > .05$] or the VM [$F(3,30) = 2.12$, $p > .05$] conditions. These results and the fact that Session 20 CM performance consistently exceeded Session 1 CM performance indicate that the previously noted attenuation of memory set size

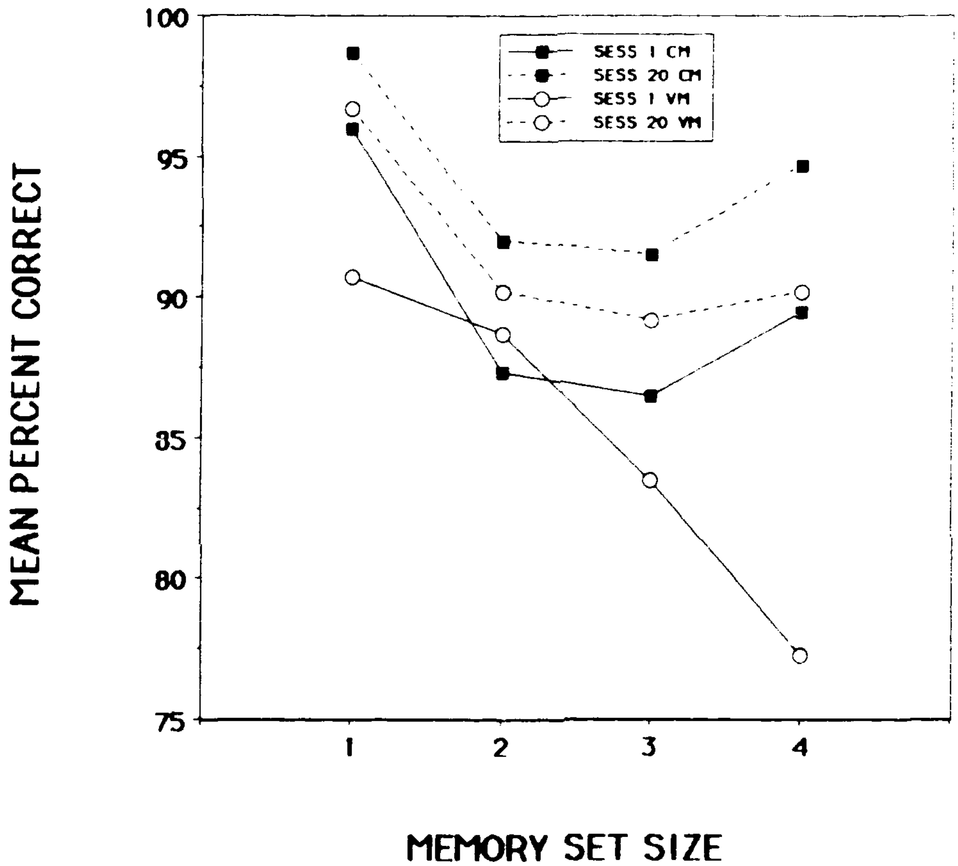

Figure 4. Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Training Session.

effects in Session 20 CM versus VM reaction times cannot be attributed to a reliable speed-accuracy tradeoff in the CM condition. Consequently, these accuracy results are also consistent with the development of some level of automatic processing in the CM condition.

Discussion

The results of this experiment support the capability of subjects to develop automatic processing with static spatial patterns under conditions in which target and distractor patterns are not distinguished by differences in category membership. This experiment therefore extends the results of the earlier Eggemeier et al. (1990) spatial pattern work, and indicates that the advantages of automatic processing can be expected to accrue to tasks that require memory search for non-categorized spatial pattern information.

Experiment 2
Development of Automatic Processing in a Task Requiring the Search for Complex Spatial Patterns

Purpose

Experiment 1 demonstrated evidence of automatic processing in a memory search paradigm with spatial patterns that were static representations of materials that must be processed by C2 operators. The actual search tasks performed by C2 operators, however, typically require that dynamic (as opposed to static) spatial patterns be processed. C2 tasks also usually require that critical or target patterns be identified on a search display that can include both distractor patterns and random visual background noise that are unrelated to either target or distractor patterns. The dynamic patterns processed by C2 operators are spatial configurations, presented on a system display, that represent either radar or satellite returns

associated with a moving target (e.g., aircraft, weather phenomena). Therefore, these patterns exhibit characteristics of apparent movement.

Although the results of previous research are important in establishing that automatic processing does occur in static analogs of C2 tasks, it is also important to extend the work with static representations to the type of dynamic patterns that exhibit apparent motion characteristics and that typify the processing requirements found within C2 systems.

In the above-referenced investigation of automatic processing with such dynamic spatial patterns, Lawless and Eggemeier (1990) examined performance with a weather pattern detection task requiring that subjects search a display for complex spatial patterns that exhibited apparent motion characteristics. Subjects completed 768 training trials under either CM or VM mapping conditions. In addition to target and distractor patterns that exhibited apparent motion characteristics, random visual background noise was also presented on the search display and was progressively increased across the 12 days of training. Although the CM training condition demonstrated a consistent advantage over the VM condition in the search time required to detect target weather patterns, differences between the groups were not significant.

Several factors were potentially responsible for the failure to demonstrate reliable CM vs VM differences. One such factor relates to the complexity of the weather search task and the fact that even under low background noise conditions, actual weather target patterns can be difficult to discriminate from background noise. It is therefore possible that the Lawless and Eggemeier (1990) subjects were impaired in their capability to learn the distinction between target and distractor patterns because of the presence of background noise on search displays throughout training. This suggests the possibility that reliable differences

between CM and VM performance might have developed if training had initially taken place under conditions of no noise, that afforded the opportunity to allocate possibly more processing resources to the target-distractor discrimination aspect of the task.

Therefore, the present experiment was conducted to investigate the effect of training under a no-background-noise condition on the capability of subjects to perform the same weather search task used by Lawless and Eggemeier (1990). Both CM and VM conditions were included in the present experiment, and the amount of training was set at approximately the same level used in the Lawless and Eggemeier (1990) work. However, background noise was eliminated throughout the course of the training to investigate the levels of performance that would result with training under lower search workload levels than were employed in the previous study.

Method

Subjects. Twelve University of Dayton students participated as paid subjects in this experiment. Subjects were paid $4.00 per hour for their participation, plus a $1.00 per hour bonus for appearing on time for each scheduled training session.

Apparatus. Macintosh IIx computers with extended keyboards and standard mouse interfaces were used to simulate a weather satellite display. The workstations presented the stimuli, recorded subject responses, and controlled the experiment. A high-resolution, 19-inch PCPC color monitor presented the target and distractor stimuli. Subjects used the standard mouse with a single button to superimpose a cursor on a target stimulus, and activated the button to indicate the selection of the target pattern superimposed by the cursor.

The stimulus presentation and response system had been programmed in Smalltalk 80 programming language by Systems Research Laboratories, Inc. under contract with the Air Force Human Resources Laboratory (AFHRL).

Stimuli. Stimuli represented weather phenomena (e.g., severe thunderstorm, tornado) and consisted of multi-element dot patterns with apparent motion characteristics.

Each walking-dot pattern was a set of dots that grew in linear form from one to six elements. The dots that made up each walking-dot pattern were illuminated for approximately 1/8 second and were not illuminated during the remainder of the 1-second interval. The resultant flashing was continuous, with a flash occurring approximately every second. Updates or so-called refreshes to the pattern occurred every 7 seconds. When a refresh occurred, a new dot was added to the end of the previous linear pattern. After several refreshes, a pattern of dots was formed, with each dot briefly flashing on and off in succession during each 1-second interval. As a consequence of illuminating the dots in the order in which they appeared during successive updates, the dot elements appeared to "walk" in a line across the screen.

Both targets and distractors had apparent motion characteristics that varied along several dimensions. One such dimension concerned the separation between successive dots. This separation varied between patterns, with relatively large levels of separation representing rapid movement of a target and relatively little separation indicating a near-stationary target. This separation could increase or decrease as successive dots appeared, representing either acceleration or deceleration. The heading or direction of apparent movement of the pattern was also varied at random. The intensity of a target was indicated by the apparent brightness of a dot or dots in the pattern. Apparent brightness was created by adding a row of pixels to the

particular dot or dots. Each pattern had a fixed brightness level.

In conceptualizing the dynamics of the target weather patterns, it is useful to consider what would be happening from a weather monitoring system perspective. In the system whose dynamics are simulated, a satellite is tracking weather patterns within the state of Ohio. The system display operates at a refresh rate of 7 seconds. This refresh rate represents the time required for the satellite to rotate about its own axis and acquire new data. For example, with a refresh rate of 7 seconds, the display would flash the previous eight scans of data every second until the occurrence of a scan 7 seconds later. At this time, the display would be updated and the data from the first scan of the previous eight would be dropped and the new information added. The effect is presentation of eight time periods. When a refresh occurs, the first time period drops out of the display and a new set of data appears, thereby permitting seven historical presentations of the most recent data points to be displayed.

When a severe thunderstorm is first detected, for example, the system displays a single dot in the eighth time period. If the thunderstorm has moved when the satellite completes its next scan, the system display would present the new position following the previous dot in successive time periods. After eight scans of the thunderstorm, the display would show a walking-dot pattern of eight dots.

For each CM subject, the target set consisted of three walking-dot patterns that represented three different weather phenomena. The CM distractor set also included three walking-dot patterns that represented weather phenomena. The combined sets created a single set of six weather patterns. Targets and distractors were selected at random from the combined set in the VM condition. Stimuli that served as targets and distractors for

one CM subject served as distractors and targets, respectively, for an additional CM subject. Therefore, three different target/distractor and distractor/target sets were employed in CM conditions across the experiment. Each CM subject had a VM counterpart that received the same six stimuli as targets or distractors across trials. The same weather patterns therefore served as targets/distractors in both CM and VM conditions. All stimuli had apparent motion characteristics and varied in both distance between successive dots and in intensity to create a walking-dot pattern. This experiment employed the same pattern stimuli used in the Lawless and Eggemeier (1990) work.

Procedure. Subjects participated in five training sessions across five days of training. Each session included five blocks of 32 training trials, for a total of 160 trials per session and 800 total acquisition trials. Subjects were given the opportunity for a short break after each block of 32 trials.

Six subjects were assigned to the CM group and six to the VM group. All subjects were asked to maintain a minimum accuracy level of 75% while attempting to detect target patterns as rapidly as possible.

Each trial began with the presentation of a target pattern to the subject. Subjects were permitted to view the target display as long as they wished, and terminated the display by pressing the button on the mouse interface. This target display showed the physical characteristics of the target pattern, including the separation of target elements and the pattern of movement. However, the target display did not illustrate the randomly selected heading of the target as it was to appear on the subsequent search display. This information was omitted to ensure that target heading was not used as a search cue, leaving only target characteristics as cues.

The target display was replaced by a search display that consisted of an outline of a map of the state of Ohio, and the target and two distractor walking-dot patterns. Target and distractor patterns were presented at random locations within the outline of the map of Ohio. The time required by the subject to identify the target pattern through use of the mouse interface was recorded as one dependent variable. This response time was the time between the appearance of the first dot in the target and the correct selection of the target by the subject using the mouse interface. This time was recorded in units that approximated real time and that were consistent across experimental conditions.

In addition to response time, false alarms were recorded. A false alarm occurred when a subject superimposed the cursor on one of the distractor patterns and depressed the response button. Response times were collected only for correct target identifications or so-called "hits." If a subject failed to find the target in 40 seconds, the trial was recorded as a miss. Because there was a target pattern present on each trial, there were no correct rejections.

Several different types of feedback were provided to the subjects. On trials in which a hit occurred, the trial ended and a message which indicated that the target had been successfully identified was displayed. If the subject failed to find the target in the 40-second time period, the trial ended automatically and the target was highlighted. The highlighting consisted of a box around the target and was provided to show the subject the target that had been missed. If the subject identified a distractor pattern as the target during a trial, a false alarm message was displayed; and, if time permitted, the trial continued.

Additional feedback was provided for the subject at the end of every block of eight trials. This feedback consisted of mean

response time for hits, the number of misses, the total number of false alarms, and the percent accuracy for that block of trials. The percent accuracy measure was based on the number of trials in which no error (i.e., a false alarm or a miss) had occurred.

In addition to block summary feedback, mean response time and percent accuracy feedback for the preceding session were provided to subjects at the beginning of the second through the fifth training sessions.

Design. Two independent variables were included in the design: (a) target/distractor mapping, and (b) training sessions. Target/distractor mapping was either CM or VM, and represented a between-subjects variable. Each group completed five sessions of training trials across the five days of training.

Results

Response Time. Mean response time to detect the target pattern as a function of CM/VM condition and training session is shown in Figure 5. The means presented in Figure 5 are based on errorless trials in which no false alarms occurred. As depicted in the figure, both CM/VM condition and sessions had an effect on response time. Although CM response times were initially higher than those of the VM condition, the CM group demonstrated a consistent advantage over the VM group during Sessions 2 through 5. Another notable aspect of the data depicted in the figure is the tendency for both groups to improve over all five acquisition sessions. It appears that neither group had reached a stable level of performance at the conclusion of training, and therefore further improvements might have been obtained with additional training sessions.

A 2-x-5 ANOVA was performed on the response time data to analyze the effects of mapping condition (CM vs VM) and training session (1-5). Mapping condition was a between-subjects variable,

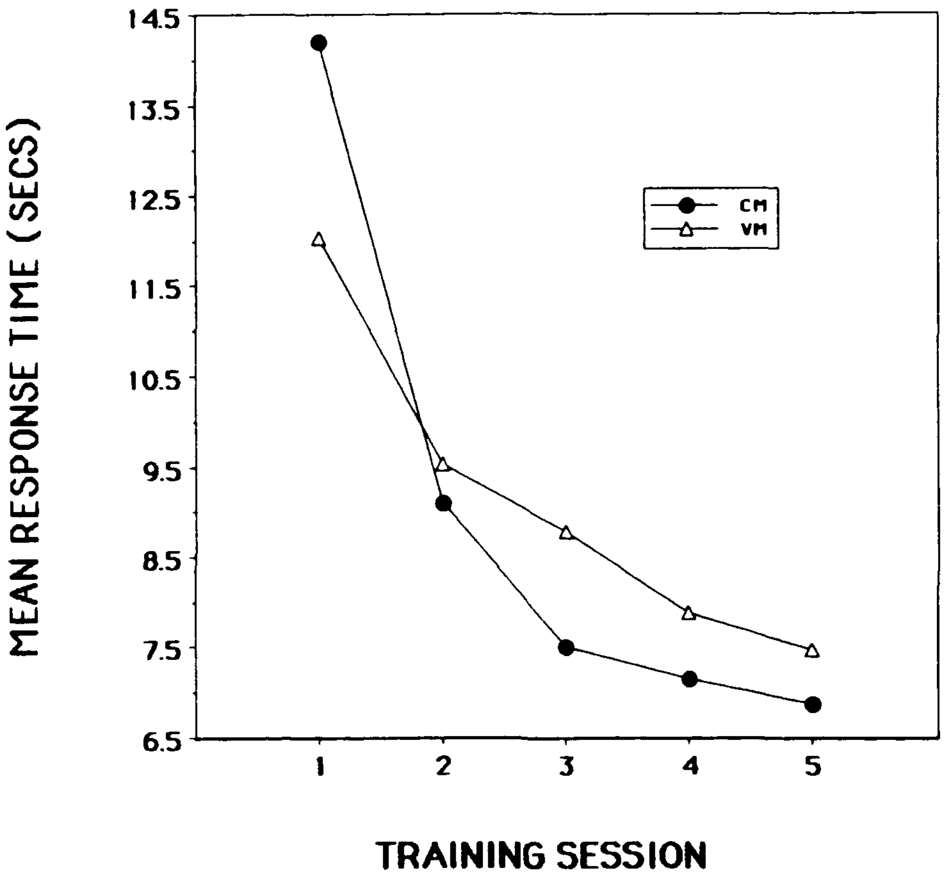

Figure 5. Mean Response Time as a Function of Mapping Condition and Training Session.

whereas training session was a within-subjects variable. This analysis indicated that though the main effect of training session [$F(4,40) = 69.95$, $p < .001$] was significant, the main effect of mapping condition [$F(1,10) = 0.04$, $p > .05$] was not. In addition, the analysis showed that the interaction of CM/VM and training session [$F(4,40) = 4.05$, $p < .01$] was significant. The failure of the CM/VM main effect to reach significance indicates that overall, the mapping condition variable failed to reliably affect response time in this task. Therefore, although CM performance did demonstrate an advantage over VM performance across the final four sessions of training, this advantage was not reliable.

Tests of simple main effects of mapping condition were conducted at each session to further investigate the reliable CM/VM x training session interaction. These tests also failed to demonstrate any reliable effect of mapping condition, suggesting that the interaction reflects the previously noted reversal in performance trends in the CM and VM conditions that occurred across training sessions.

In addition to analyses of mean response time, the variability of response time was also analyzed to determine if there were differences between mapping conditions as a function of this aspect of performance. As noted above, CM performance tends to be less variable than VM performance, and this could represent an important dimension in a task, such as the weather search, that requires rapid identification of critical patterns.

Figure 6 shows mean standard deviation of response time as a function of mapping condition and training session. As is clear from the figure, CM performance was once again poorer than VM performance over the initial sessions of training. However, by Session 3, CM performance was less variable than VM performance, and it maintained this advantage during the remainder of the training sessions.

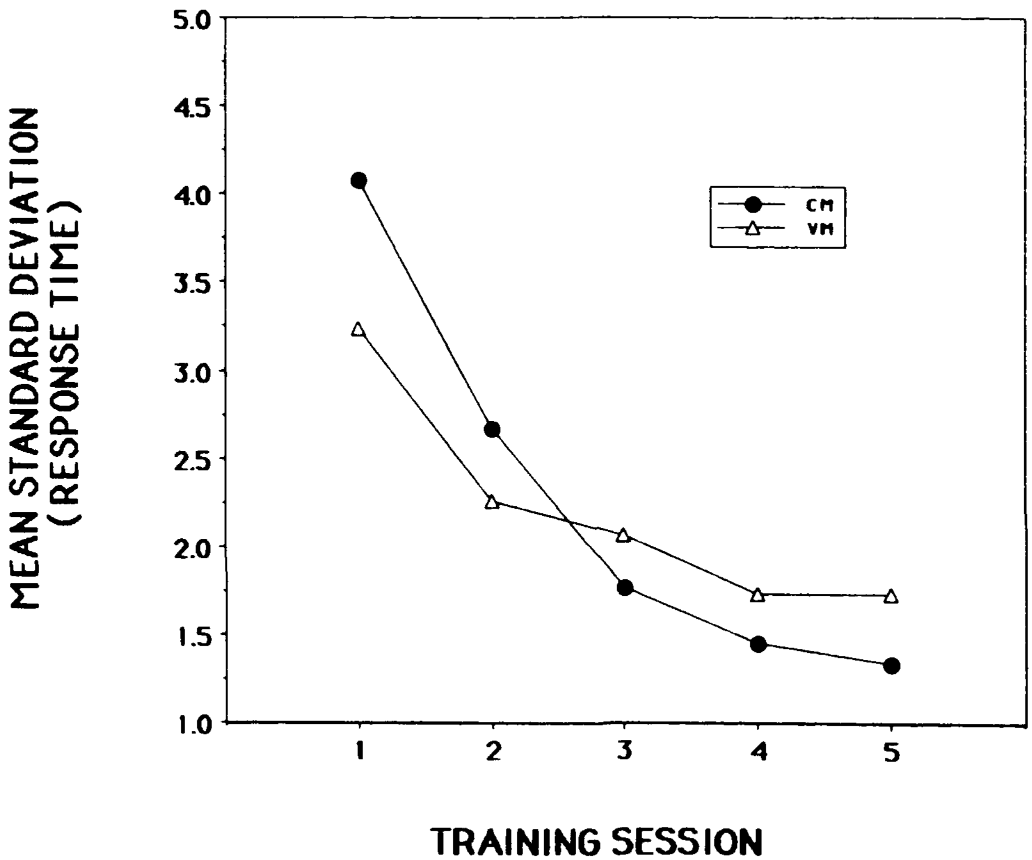

Figure 6. Mean Standard Deviation of Response Time as a Function of Mapping Condition and Training Session.

A 2-x-5 ANOVA was performed on the response time standard deviation data to analyze the effects of CM vs VM mapping and training sessions (1-5). This analysis demonstrated a significant main effect of training session [$F(4,40) = 49.48$, $p < .001$], but failed to show a significant effect of mapping condition [$F(1,10) = 0.04$, $p > .05$]. The analysis also showed that the CM/VM x training session interaction was significant [$F(4,40) = 4.74$, $p < .01$]. Tests of simple effects of mapping condition were conducted at each session to further investigate the reliable CM/VM x training session interaction. These ANOVAs also failed to demonstrate any significant effect of mapping condition. This pattern indicates that the reliable interaction reflected the previously described reversal in reaction time variability that occurred in the CM versus the VM conditions across the five training sessions.

The results of this analysis therefore parallel those of the mean response time analysis and indicate that even though the CM group demonstrated a consistent advantage over the VM group during the latter stages of training, there was no reliable effect of mapping condition on performance. Once again, a high degree of learning was exhibited in both mapping conditions as training sessions progressed.

Accuracy of Responding. Figure 7 shows mean percent correct responses as a function of CM/VM group and training session. The means illustrated in Figure 7 are based on trials in which no error (i.e., false alarm, miss) occurred. As is clear from the figure, response accuracy improved considerably after Session 1, and was consistently high in both CM and VM groups. Differences between these groups were minimal.

A 2-x-5 ANOVA comparable to that performed on the reaction time data was conducted on the accuracy data. This analysis demonstrated no main effect of mapping condition [$F(1,10) = 0.02$, $p > .05$]; a significant main effect of training session [$F(4,40) =$

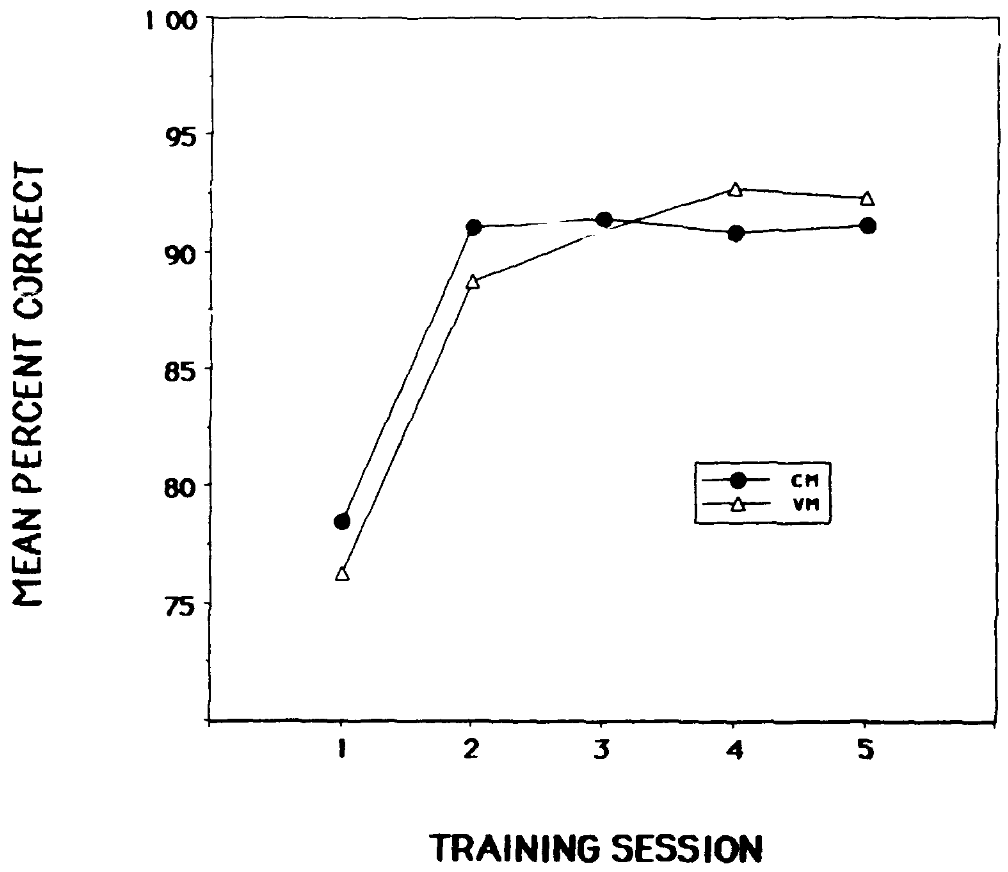

Figure 7. Mean Percent Correct as a Function of Mapping Condition and Training Session.

24.49, $p < .001$]; and no interaction of mapping condition x training session [$F(4,40) = 0.59$, $p > .05$]. The main effect of training session indicates that the trend for increased accuracy in both mapping groups, which is apparent in Figure 7 is significant. The failure to find significant CM versus VM differences indicates that there were no reliable differences in accuracy of performance as a function of mapping condition. An additional ANOVA performed with a response accuracy data base that included trials on which false alarms occurred also failed to demonstrate any reliable effect of mapping condition on the number of correct responses.

In addition to percent correct responses, the mean false alarms per trial were computed as an index of response accuracy, and are illustrated as a function of mapping condition and training session in Figure 8. As is clear from the figure, the mean false alarms per trial were minimal in both CM and VM conditions, and tended to remain relatively stable in both groups after the initial acquisition sessions.

A 2-x-5 ANOVA that examined the effects of mapping condition and training sessions on the false alarm data indicated that once again, the main effect of training sessions [$F(4,40) = 20.15$, $p < .001$] was significant and that the main effect of mapping condition [$F(1,10) = .02$, $p > .05$] was not. The mapping-condition-x-training-session interaction [$F(4,40) = 0.72$, $p > .05$] also failed to demonstrate significance.

Discussion

The results of this experiment indicate that although the CM condition exhibited a response time advantage over the VM condition during the latter sessions of training, the differences in performance were not reliable. Therefore, the present results do not indicate that automatic processing had developed in the CM

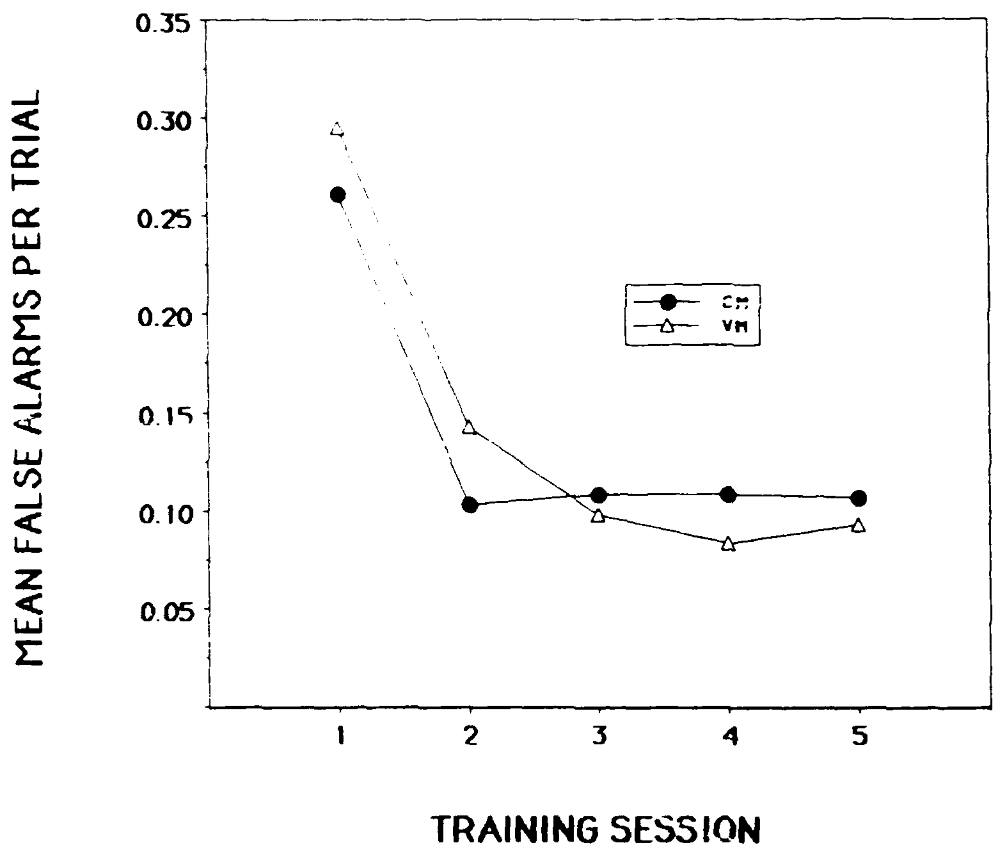

Figure 8. Mean False Alarms Per Trial as a Function of Mapping Condition and Training Session.

condition. The demonstration of a response time advantage in the present study is consistent with the results of Lawless and Eggemeier (1990), who also reported nonsignificant CM advantages in response time variability and accuracy as well. The similarity in results between this study and those of Lawless and Eggemeier (1990) suggests that the presence of background noise was not the principal factor in the failure to demonstrate CM-VM differences in the latter experiment.

There are a number of potential reasons for the failure to demonstrate CM-VM differences in the present experiment. One possible difficulty relates to the relatively few number of acquisition trials (800) used. As discussed earlier, automatic processing can take thousands of training trials to develop. Because it does not appear that stable levels of performance had been achieved on the response time measure at the conclusion of the current training sessions, it is possible that more extensive training would have provided evidence of automatic processing in the CM group.

A second set of factors that may have precluded the demonstration of CM-VM differences concerns the multi-stage nature and complexity of the weather pattern search task. The present task, for instance, required that subjects search for target patterns within a relatively large area on a CRT screen that was bounded by the outline of the state of Ohio. The search process involved in this task was therefore more complex and potentially more variable than the search processes typically associated with laboratory paradigms, where the boundary of search is usually restricted to a much more circumscribed area than that used here. It is typical in laboratory paradigms, for instance, to provide a fixation cue to direct the subject's attention to a limited search area, and then to provide a number of display alternatives in close proximity to one another as the search set. The search area associated with the current task was much larger than the usual laboratory norm, and was quite

possibly associated with more complex search strategies that could have added considerable variability to performance and may have contributed to the inability to detect reliable CM-VM differences.

Likewise, the response requirements of the current task were considerably more complex and potentially more variable than those associated with most laboratory paradigms used to investigate automatic processing. The majority of these paradigms use a relatively simple discrete response such as a button press for subjects to indicate that a target has been identified. The requirement to coordinate the movement of the cursor with that of the mouse interface, and the continuous nature of the response in the present paradigm, imposed heavier motor control demands on subjects than those of the typical paradigm. Once again, the potentially high variability associated with this component of the weather search task constitutes a possible factor in the inability to demonstrate CM-VM differences.

A third possible factor in the failure to demonstrate differences in CM vs VM performance is the complex nature of the dynamic weather pattern stimuli used. Although the results of Experiment 1 and previously reported data concerning static spatial patterns (Eggemeier et al., 1990) indicate that automatic processing can be established with such patterns, it is possible that the complex nature of the dynamic spatial patterns used here either precludes the development of such processing or slows it considerably.

One approach to gaining a possibly more straightforward evaluation of the capability to develop automatic processing with dynamic spatial pattern information would be to examine the effect of extensive training on performance in a paradigm that reduced the levels of search and response load present here. Experiment 3 was therefore conducted to evaluate the development of automaticity with dynamic spatial patterns in such a paradigm.

Experiment 3
Development of Automatic Processing in a Memory/Visual Search Task Requiring the Processing of Complex Spatial Pattern Information

Purpose

The results of Experiment 2 failed to demonstrate significant differences between CM and VM search conditions within the weather pattern search task used. As discussed above, the weather pattern search task is quite complex, and involves both a more intricate search process and a more complex method of responding than has been the case in most laboratory investigations of automatic processing. In the failure to find significant CM-VM performance differences, one possible factor outlined previously is the variability in performance that could be associated with the complex search and response requirements of the weather search paradigm.

The present experiment investigated the effect of extensive practice on performance in a memory/visual search paradigm with a set of dynamic spatial patterns similar to those used during Experiment 2. Six of the eight dynamic spatial patterns used in Experiment 2 were also used in this experiment.

A number of changes were introduced into the procedure for the present experiment to reduce the search and response requirements present in the weather search paradigm. First, a combined memory search/visual search paradigm was implemented. This paradigm included sequential presentation of memory set patterns, followed by a search display divided into quadrants. In the present experiment, a target and distractor pattern appeared in each of two quadrant elements, thereby reducing search requirements from the entire area bounded by the shape of the state of Ohio to the two relevant elements of the quadrant.

Response requirements were reduced by requiring subjects to make a discrete key press to indicate the element of the quadrant in which the target had appeared.

Some procedural differences in presentation of the patterns were also implemented to facilitate the capability of subjects to study and respond to the patterns. First, instead of permitting the pattern to grow into its final format with progressive additions of individual elements as in Experiment 2, the total pattern with its apparent motion characteristics was presented for study by the subject and eventual testing. Also, although different orientations of patterns were presented across trials, the memory set pattern and subsequent test pattern were presented in the same orientation.

Method

Subjects. Sixteen University of Dayton students participated as subjects in this experiment. Subjects were paid $4.00 per hour for their participation, plus a $1.00 per hour bonus for appearing on time for each scheduled training session.

Apparatus. Macintosh IIx computers with extended keyboards were used to present the stimuli, record subject responses, and control the experiment. A high-resolution 19-inch PCPC color monitor presented the target and distractor stimuli. Subjects used the computer keyboard to provide responses.

The stimulus presentation and response system had been programmed in Smalltalk 80 programming language by Systems Research Laboratories, Inc. under contract with AFHRL.

Stimuli. Stimuli represented the same type of weather phenomena (e.g., severe thunderstorm, tornado) that had been researched in Experiment 2, and consisted of multi-element dot patterns with apparent motion characteristics.

Each walking-dot pattern was a set of dots that included from 3 to 8 elements. Both targets and distractors had apparent motion characteristics that varied along several dimensions. One such dimension concerned the separation between successive dots. This separation varied between patterns with relatively large levels of separation representing rapid movement of a target, or relatively little separation indicating a near-stationary target. The heading or direction of apparent movement of the pattern was also varied at random. The intensity of a target was indicated by the apparent brightness of a dot or dots in the pattern. Apparent brightness was created by adding a row of pixels to the particular dot or dots. Each pattern had a fixed brightness level.

For each CM subject, the target set consisted of four walking-dot patterns intended to represent the type of weather phenomena simulated in Experiment 2. The CM distractor set also included four walking-dot patterns representative of weather phenomena. The combined sets created a single set of eight weather patterns. Targets and distractors were selected at random from the combined set in the VM condition. The same spatial patterns therefore served as targets/distractors with both CM and VM conditions. Stimuli that served as targets and distractors for one CM subject served as distractors and targets, respectively, for an additional CM subject. Therefore, four different target/distractor and distractor/target sets were employed in CM conditions across the experiment. All stimuli had apparent motion characteristics and varied both in distance between dots and in intensity to create walking-dot spatial patterns.

Procedure. Subjects participated in 12 training sessions across 12 days of training. Each session included seven blocks of 20 training trials, for a total of 140 trials per session and 1,680 total acquisition trials.

Eight subjects were assigned to the CM group and eight to the VM group. All subjects were asked to maintain a minimum accuracy level of 90% while attempting to identify the target as rapidly as possible.

Each trial began with the presentation of a memory set to the subject. Memory set size varied from one to four patterns within blocks of trials. Each memory set pattern was presented individually in the center of a square that was 10 mm on a side. The complete pattern was presented for subjects to study; therefore, patterns did not exhibit the growth characteristics over time that were present in the patterns used during Experiment 2. The presentation of weather patterns in the memory set was sequential, and each pattern was numbered in accordance with its sequence of presentation on a particular trial. Subjects were permitted to study each pattern for a maximum of 10 seconds. The presentation of a pattern could also be terminated by the subject by pressing the return key on the keyboard. The memory set display demonstrated the physical characteristics of the target pattern, including the separation of target elements and the pattern of movement.

The final pattern in the memory set was replaced with a search display divided into quadrants that were 10 mm on a side. This quadrant set was presented in the center of the CRT screen. Search display size was held constant at two patterns, and these appeared in the top two quadrants of the search display. Each search display included one of the memory set items as a target pattern in one of the upper two quadrants, and a nontarget or distractor pattern in the other upper quadrant. As was the case with the memory set display, the complete pattern was presented to the subject and patterns did not exhibit growth characteristics. The quadrant in which the target appeared was chosen at random on a trial-by-trial basis.

Subjects responded by depressing the button on the extended keyboard that corresponded to the quadrant in which the target pattern was displayed. The "7" and "9" keys on the numeric keypad were relabeled "1" and "2" respectively, to correspond with the numbers that appeared in the corner of each relevant quadrant. The time required by the subject to identify the target pattern by depressing the appropriate key was recorded. This reaction time was the time between the appearance of the target/distractor patterns and the selection of a quadrant by the subject. This time was recorded in units that approximated real time, and that were consistent across experimental conditions.

Each trial ended with the selection of a quadrant by the subject or after a period of 10 seconds, whichever occurred first. If the correct quadrant was chosen by the subject, a message to that effect appeared on the screen with the instruction for the subject to depress the return key to continue with the next trial. If the incorrect quadrant was chosen, a message to that effect was presented and the subject was instructed to depress the return key to continue. The number of correct and incorrect trials was also recorded.

Several different types of feedback were provided to the subjects. In addition to a message concerning whether the response on each trial had been correct or incorrect, summary feedback was provided for the subject at the end of every block of 20 trials. This feedback consisted of mean response time for correct responses and the percent correct for that block of trials.

In addition to block summary feedback, mean response time and percent accuracy feedback for the preceding session were presented to subjects at the beginning of the second through twelfth training sessions.

Design. Three independent variables were included in the design: (a) target/distractor mapping, (b) memory set size, and (c) training sessions. Target/distractor mapping was either CM or VM, and represented a between-subjects variable. Memory set size varied from one to four patterns and was manipulated within blocks of trials. Each group completed 12 sessions of training trials across the 12 days of training.

Results

Reaction Time. Mean reaction time to identify the target pattern as a function of CM/VM condition and training sessions is shown in Figure 9. The means presented in Figure 9 are based on trials in which the correct response was made. As depicted in the figure, both CM/VM condition and training sessions had substantial effects on response time. CM performance was superior to VM performance across training sessions, but both mapping conditions demonstrated considerable improvements in performance as training progressed.

A 2-x-4-x-12 ANOVA was performed on the reaction time data to analyze the effects of mapping condition (CM versus VM), memory set size (1-4), and training session (1-12). Mapping condition was a between-subjects variable, whereas memory set size and training sessions were within-subjects variables. This analysis indicated that the main effects of mapping condition [$F(1,14) = 15.05$, $p < .005$], training sessions [$F(11,154) = 103.10$, $p < .001$], and memory set size [$F(3,42) = 76.99$, $p < .001$] were significant. In addition, the analysis showed that the CM/VM x memory set interaction [$F(3,42) = 6.21$, $p < .01$], the training-sessions-x-memory-set interaction [$F(33,462) = 5.77$, $p < .001$], and the CM/VM-x-memory-set-x-training-sessions interaction [$F(33,462) = 2.33$, $p < .001$] were reliable.

As discussed previously, a criterion that can be used in a memory search paradigm to assess the development of automatic

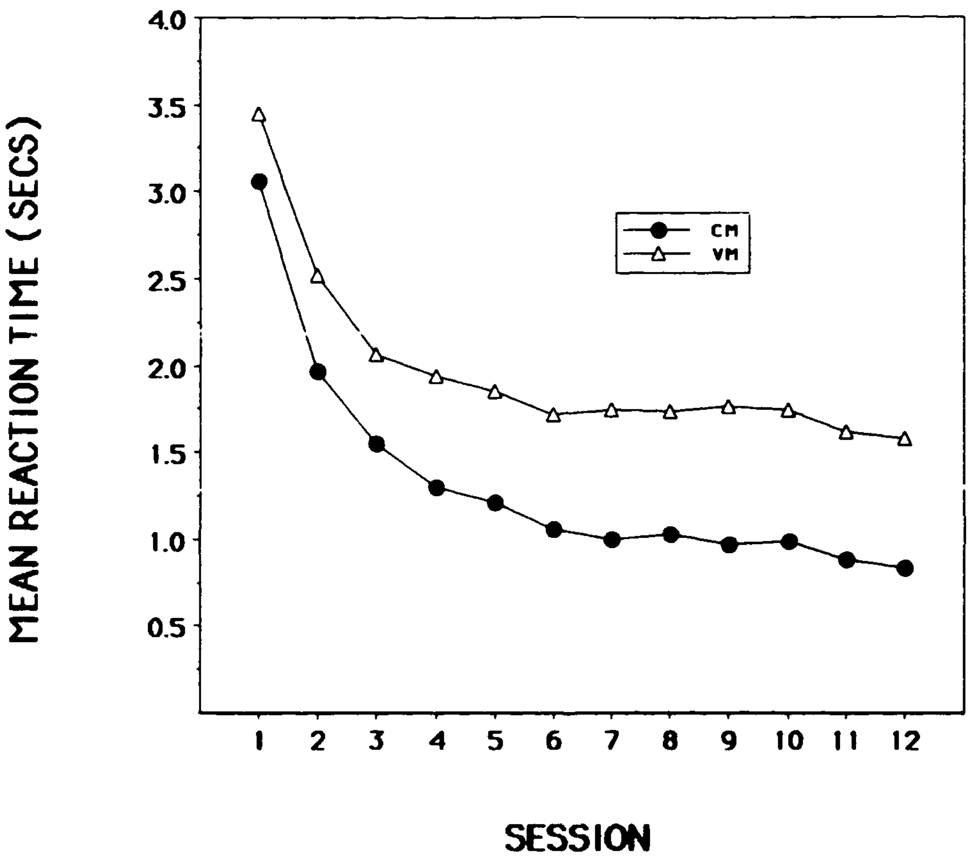

Figure 9. Mean Reaction Time as a Function of Mapping Condition and Training Session.

processing concerns a greater reduction in the effect of memory set size on performance in the CM relative to the VM condition as training progresses. The significant CM/VM-x-memory-set-x-training-sessions interaction reported above is consistent with the presence of a differential effect of memory set size on CM and VM performance as a function of training. Figure 10 illustrates the effect of memory set size on reaction time in the CM and VM groups for both the first and last sessions of training. As illustrated, memory set size had a substantial effect on both CM and VM performance during the first training session. By the end of training, however, the effect of memory set on reaction time had been markedly attenuated in the CM group relative to the VM group.

Following the significant CM/VM-x-memory-set-x-training-session interaction, tests of simple effects of memory set on performance within the CM group and within the VM group were conducted on the Session 1 data to assess the effect of memory set on reaction time at the beginning of training. This analysis showed that there was a significant effect of memory set within both the CM [$F(3,42) = 17.76$, $p < .001$] and VM [$F(3,42) = 11.01$, $p < .001$] conditions. A Tukey-A post-hoc multiple comparison test indicated that within the CM group, the reaction times associated with memory set size one differed reliably ($p < .05$) from all other memory set sizes. The same pattern of results was obtained in an application of the Tukey-A procedure to the Session 1 VM group data. Memory set size therefore had similar effects on reaction time performance in both the CM and VM groups during the initial training session.

Comparable tests of simple effects were also conducted to assess the effect of memory set size on CM and VM reaction time performance during Session 12. These analyses indicated that memory set continued to reliably affect both CM [$F(3,42) = 3.13$, $p < .05$] and VM [$F(3,42) = 44.10$, $p < .001$] performance during the last session of training. A Tukey-A multiple comparison test

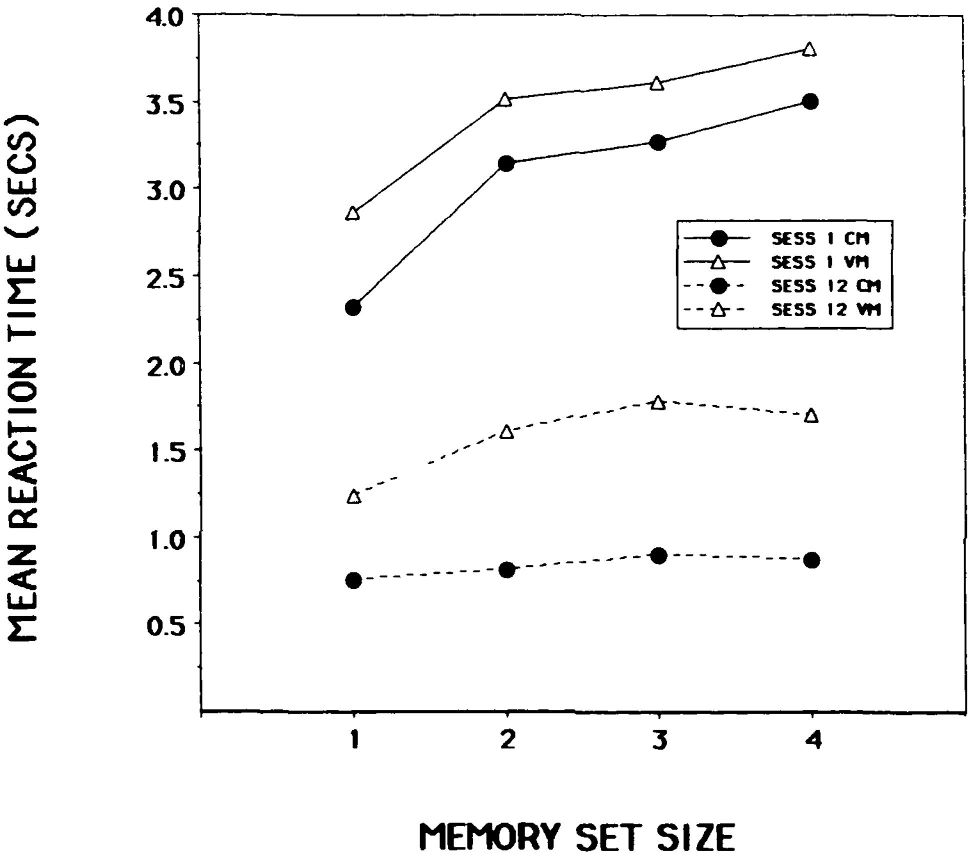

Figure 10. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Training Session.

showed that within the CM group, reaction times associated with memory sets of three patterns differed significantly from those that included one pattern. Within the VM group, however, a Tukey-A test demonstrated that reaction times of memory set size one were significantly different from those associated with all other memory set conditions, and that memory sets which included three patterns produced reliably higher reaction times than those which included two patterns. The results of these analyses therefore confirm the trends noted in Figure 10, and indicate that with practice, the effects of memory set size were attenuated more substantially within the CM condition than within the VM condition.

The slopes of the functions depicted in Figure 10 were computed to further characterize the effect of memory set on reaction time. Within the CM condition, the slope of the Session 1 function was .37 second, while the slope of the Session 12 function was .04 second. In the VM group, on the other hand, the slope of the Session 1 function was .29 second, and was reduced to .16 second by Session 12. At the conclusion of training therefore, the slope of the VM function was four times as great as the slope for the CM function. These differences between CM and VM performance are therefore also consistent with the development of automatic processing in the CM group.

Accuracy of Responding. Figure 11 shows mean percent correct responses as a function of mapping condition and training session. As can be seen in the figure, response accuracy was consistently high in both CM and VM groups and differences between these groups were minimal.

A 2-x-4-x-12 ANOVA comparable to that performed on the reaction time data was conducted on the percent correct responses. This analysis demonstrated that the main effect of mapping condition [$F(1,14) = 2.48$, $p > .05$] was not significant, and also showed that the main effects of memory set size [$F(3,42)$

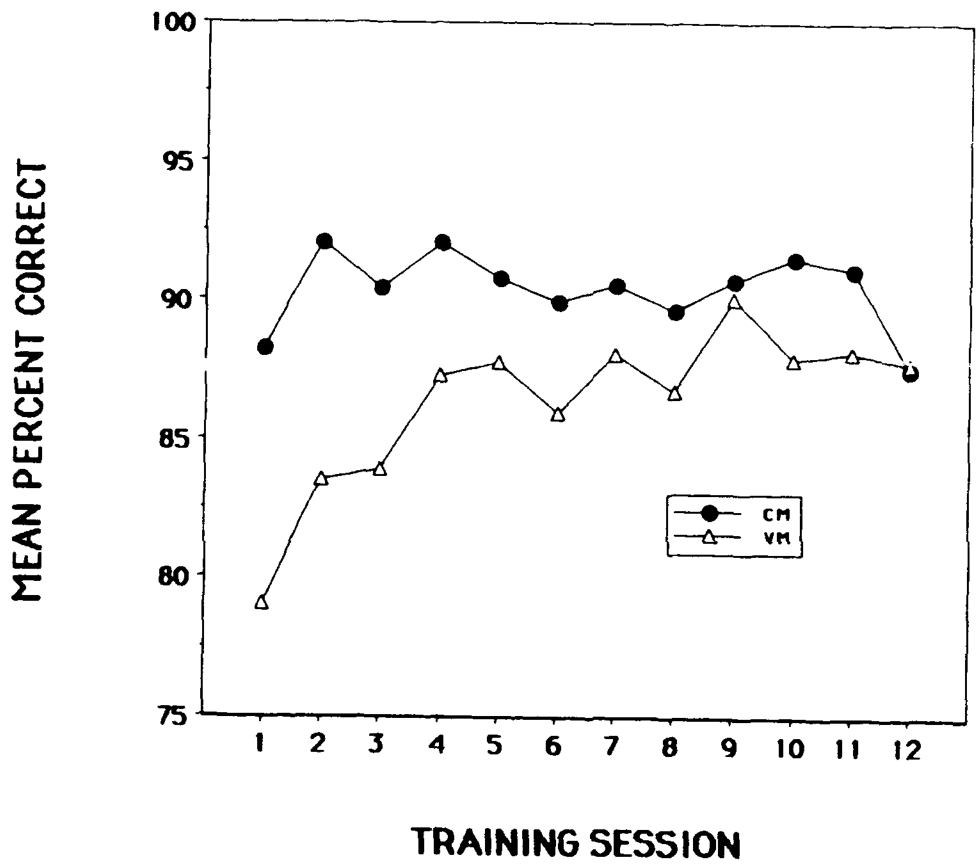

Figure 11. Mean Percent Correct as a Function of Mapping Condition and Training Session.

$= 40.26$, $p < .001$] and training session [$F(11,154) = 4.82$, $p < .001$] were significant. The results of the analysis also showed that the CM/VM x training session interaction [$F(11,154) = 3.01$, $p < .005$], the CM/VM x memory-set interaction [$F(3,42) = 9.56$, $p < .001$], the training session x memory-set interaction [$F(33,462) = 1.90$, $p < .005$] were reliable. The CM/VM-x-memory-set-x-training-sessions interaction [$F(33,462) = 1.36$, $p < .10$] approached but did not achieve significance. The failure to find a significant main effect of mapping condition indicates that overall, there were no reliable differences in accuracy of performance associated with the CM versus the VM group.

Figure 12 shows mean percent correct as a function of mapping condition in the first and last sessions of training. As is clear from the figure, the CM group showed higher levels of performance than the VM group in Session 1, and increases in memory set size were generally associated with decrements in performance within both groups. At memory set sizes of three and four patterns, Session 12 CM performance improved relative to Session 1 CM performance and was superior to Session 12 VM performance. Session 12 CM performance did, however, show some deterioration relative to both Session 1 CM performance and Session 12 VM performance at the lower two memory set sizes.

A 4-x-2 ANOVA was performed on the CM data illustrated in Figure 12 to analyze the effects of memory set size during the first and last sessions of training. This analysis was performed to investigate the possibility that a speed-accuracy tradeoff could account for the attenuation in CM memory set effects that occurred from Session 1 to Session 12. The ANOVA indicated that the main effect of sessions was not significant [$F(1,14) = 0.18$, $p > .05$], but that the main effect of memory set [$F(3,42) = 4.40$, $p < .01$] and the session x memory set interaction [$F(3,42) = 2.90$, $p < .05$] were reliable. To further investigate the significant interaction, tests of simple main effects of session were conducted within each memory set size. These tests indicated that

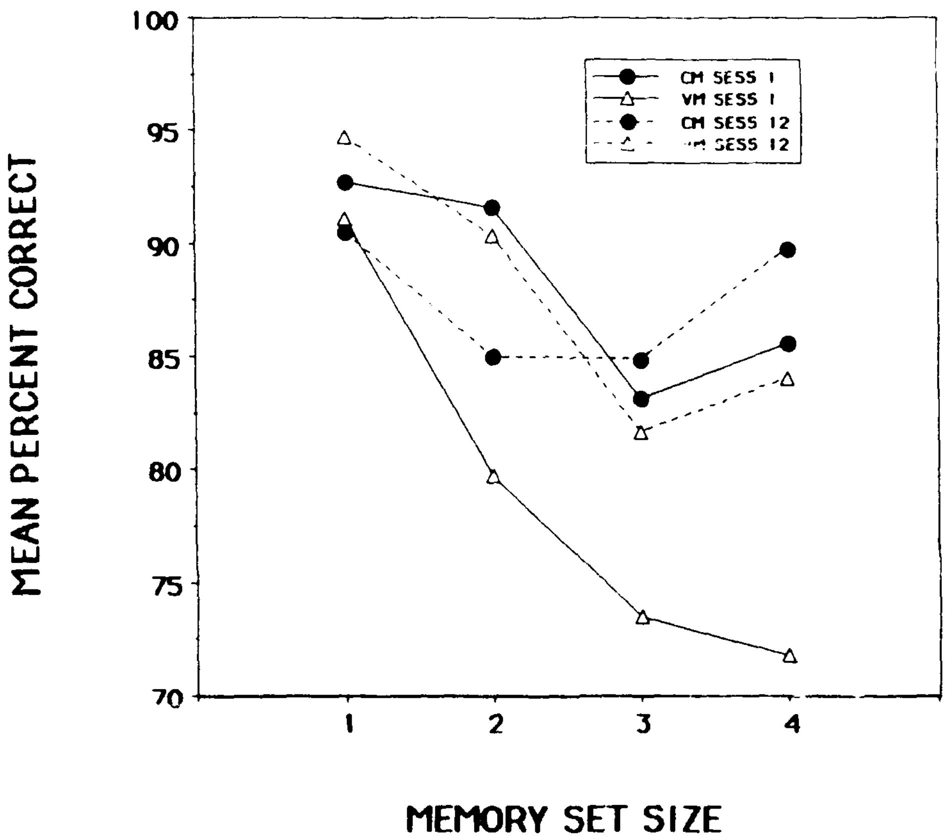

Figure 12. Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Training Session.

the only reliable effect of sessions was at memory set size two [$F(1,14) = 7.03$, $p < .02$]. This latter effect indicates that the decrement in CM Session 12 performance relative to Session 1 performance was significant, and suggests that a speed-accuracy tradeoff cannot be ruled out as the basis of reaction time improvements at memory set size two within the CM condition. However, since a speed-accuracy tradeoff does not appear to represent a viable explanation of reaction time reductions at the remaining memory set sizes, the overall pattern of the accuracy data is consistent with the development of some level of automatic processing within the CM condition.

Discussion

The results of the present experiment are consistent with the development of automatic processing in the CM mapping condition. Overall, CM performance was more rapid and accurate than VM performance. Also, the effect of memory set size on reaction-time performance was attenuated to a greater degree with practice in the CM condition than in the VM condition.

The current results indicate that dynamic spatial patterns of the type that must be processed by operators of C2 systems can be automatized, and suggest that the failure to demonstrate automatic processing in Experiment 2 and in the Lawless and Eggemeier (1990) research cannot be solely attributed to an inability of subjects to develop automatic processing with this type of material.

The present experiment manipulated memory load and maintained display load at a low level. Experiment 2 and the Lawless and Eggemeier (1990) experiment can be most appropriately classified as a visual search paradigm, and it is therefore important that future research examine the effect of manipulations in display load in the present paradigm. Such

research would provide additional data bearing on the issue of the capability to develop automatic processing with dynamic spatial pattern information in a paradigm that closely parallels the demands of some C2 systems.

Experiment 4
Development of Automatic Processing in a Task Requiring the Processing of Complex Alphanumeric Rule-Based Information

Purpose

In addition to the spatial pattern information investigated in Experiments 1-3, some Air Force C2 systems require the operator to rapidly process complex alphanumeric information in the form of the rule-based type of task discussed above. As noted earlier, these rules consist of the conjunction of an acronym or sequence of letters that stands for a system parameter and a range of numerical values associated with that parameter. Although the capability to automatize the processing of such rule-based alphanumeric information is of great potential importance to operators of C2 systems, little information is available in the current literature to address automatic processing of such complex alphanumeric materials.

Therefore, the purpose of Experiment 4 was to investigate the effect of training under a CM condition and under a variant of a VM condition on performance with this second type of information that must be processed by Air Force system operators. This experiment employed the same memory search paradigm as that used in Experiment 1. As indicated previously, this type of memory search is a component of many operator tasks in air weapons control and event detection systems, and requires rapid and accurate responding.

The memory search task in this experiment used target and distractor sets which consisted of complex alphanumeric rules that included both a three-letter sequence (e.g., SNK, GLX) and a range of numerical values (e.g., 45-55, 25-35) associated with a particular letter sequence. For example, one rule might take the form of "SNK 45-55," while a second rule could be of the form "GLX 25-35." These rules were the items that appeared in the memory set, and a probe item consisted of a single conjunction of a letter sequence and numerical value that either represented an exemplar of the rule or did not. For example, the probe item "SNK 47" would represent an exemplar of SNK 45-55, in that the numerical value 47 falls within the specified range for SNK, whereas "SNK 37" would not represent an exemplar of the rule, as the numerical value falls outside the specified range for SNK.

Both CM and VM conditions were included in the experiment. Under CM conditions, certain rules and their associated exemplars remained targets throughout training for an individual subject, whereas exemplars of other rules served as distractors across training sessions. In the VM condition, rules and their associated exemplars alternated as either targets or distractors across training trials.

It is important to note at this point that there are several levels of consistency within the present rule-based task. One level concerns the association between a rule and its exemplars. With the "SNK 45-55" rule discussed above, for instance, a certain set of exemplars (e.g., SNK 47, SNK 49, SNK 51) are consistently mapped to that rule. To correctly respond to a test exemplar, it is necessary that the exemplar be associated with the appropriate rule. One important aspect of skill acquisition in this task is therefore to associate a set of exemplars with the corresponding rule. Because the mapping of exemplars to rules did not change from trial to trial, this portion of the present task was consistent for both the CM and VM groups. As a

consequence, considerable improvements in performance were expected with training in the VM group within this paradigm.

A second level of consistency in this task concerns the roles played by the rules and their exemplars across training trials. Under consistent conditions, a rule and its exemplar can remain a target for an individual subject across training, whereas under inconsistent or variably mapped conditions, a particular rule can serve as either a target or distractor across acquisition trials. The present CM and VM groups differed at this level of consistency within the task, and any CM-VM differences that resulted with training would therefore reflect the effect of this level of consistency on performance.

Given the different levels of consistency that can be identified in this task, it should be noted that the present VM condition was consistent at one level, but inconsistent or variably mapped at a second level. The current VM condition is therefore a hybrid, and does not represent a pure VM condition. A pure VM condition would require that the consistency of association of particular exemplars to particular rules be eliminated across training, and would be implemented by randomly assigning system parameter designators to associated numerical values on a trial-by-trial basis during the course of training.

The different levels of consistency present in this task reflect its complexity, and mirror the same type of differences expected to be present in real-world tasks. This rule-based task was therefore considered ideal to meet the objectives of the current program, and this initial experiment with the rule-based task was designed to compare the effects of training on CM and hybrid VM performance levels.

Method

Subjects. Subjects were 16 University of Dayton students, paid $4.00 per hour for their participation. In addition to this base rate of pay, subjects were awarded a bonus payment of $1.00 per hour for appearing on time for each scheduled experimental session.

Apparatus. The experiment was controlled with a Zenith Data Systems 248 computer. The computer presented stimuli, controlled the timing of stimulus presentation, collected subject responses, and presented visual feedback at the completion of each trial and session. Subjects viewed alphanumeric stimuli on a Zenith ZCM-1490 high-resolution color monitor. Responses were made on the arrow keys located in the lower right-hand corner of a standard expanded IBM-compatible keyboard.

Procedure. Subjects performed a memory search task similar to the Sternberg (1966) paradigm. On each trial, a memory set of one to three alphanumeric rules was presented on the computer CRT screen. These rules remained on the screen until the subject pressed a designated key on a computer keyboard. When the key was pressed, a 4.5 mm x 4.3 mm fixation cross appeared in the middle of the screen for 500 ms. The fixation cross was replaced by a single test item displayed for a maximum of 2 seconds or until the subject responded.

Subjects were instructed to determine if the test item represented an exemplar of any of the previously presented rules. Subjects responded "yes" or "no" by pressing with their preferred hand a labeled response button on the keyboard. One-half of the target stimuli in each block of trials constituted exemplars of memory set rules; the other stimuli did not. Measures of both reaction time and response accuracy were recorded. Each subject was instructed to respond as rapidly as possible while

maintaining an accuracy level of 90% or higher within each session.

Visual feedback was provided to subjects at the completion of each trial. After each trial, an incorrect response was followed by a "Wrong Response" message. A correct response was followed by a "Correct Response" message and the reaction time for that trial.

Summary feedback was provided at the completion of each block of trials. This feedback provided reaction time and accuracy performance levels from the trial block that had just been completed. In addition to feedback at the completion of a block, summary feedback concerning mean reaction times and accuracy levels was provided to subjects at the completion of each session. A written tally of mean reaction time and accuracy levels across sessions was maintained to aid subjects in tracking their progress throughout the course of training.

Subjects participated in the experiment for a total of 4 days. Four training sessions, which consisted of 10 blocks of 20 trials each, were completed each day. This resulted in 800 training trials each day and a total of 16 sessions of 3,200 training trials for the entire experiment.

Stimulus Materials. Each alphanumeric rule consisted of a three-letter sequence associated with a range of numerical values. These rules were intended to represent one type of complex alphanumeric information processed by operators of certain Air Force systems. As noted above, these systems require the operator to rapidly and accurately process alphanumeric rules associated with particular system parameters.

Two sets of letter sequences composed of four stimuli each were chosen from the 50% association value letter sequences in the Underwood and Schultz (1960) norms. Sequences in each set

were chosen to be highly distinguishable from one another, such that no sequence included a letter that appeared in the same serial position in another sequence. Therefore, the first, second, and third letter of each sequence differed from the letters in the corresponding serial position in the other sequences. These sets of sequences were chosen to minimize any similarity or potential confusability between the letter sequences intended to represent the type of codes used for system parameters in C2 systems.

Each of these sets of letter sequences was paired with two numerical ranges to develop two alphanumeric rules for each letter sequence. For example, the letter sequence DXR was paired with the numerical ranges of 15-25 and 25-35 to form two rules (i.e., DXR 15-25, DXR 25-35) that used the same letter designator and which demonstrated minimal overlap in their numerical values. Four pairs of such rules were developed for one rule set designated "A", and four additional pairs were developed for a second rule set designated "B". One-half of the subjects were trained with the rule set A, and the remaining subjects were trained with set B.

Two sets of positive exemplars (targets) and two sets of negative exemplars (distractors) were specified for each rule. Each exemplar set included five numerical values. For positive exemplars, each value fell within the specified range for the rule. For negative exemplars, on the other hand, each value fell either above or below the specified range for the rule. One set of positive exemplars contained only even numbers, while the alternate set included odd numbers. The same was true of the negative exemplar sets.

Exemplar sets for rules bearing the same letter sequence were constructed such that there was overlap between the positive exemplars of one rule and the negative exemplars of the other rule. For example, DXR 18 represented a positive exemplar for the

rule "DXR 15-25," and a negative exemplar for the rule "DXR 25-35." Positive and negative exemplar sets were constructed such that four items in the positive set for one rule were represented in the negative set for the corresponding rule that shared the same letter designator, and vice versa. Appendix B includes an example of a complete rule set.

The memory sets for subjects in the CM group included only one of the two rules from each pair that shared a common letter sequence designator. CM subjects could therefore consistently respond to any individual exemplar. For a subject whose memory set contained the rule "DXR-25," for instance, a positive response was always appropriate for the exemplar "DXR 18," and a negative response was always appropriate for the exemplar "DXR 28." VM subjects, on the other hand, received both rules that shared a common letter designator on different trials. For these subjects, a positive response to "DXR 18" was correct if the memory set had included the "DXR 15-25" rule, but was incorrect if the memory set had included the "DXR 25-35" rule on that particular trial. It is important to note that both CM and VM subjects dealt with the same number of rules across the course of training, with the principal difference being that the VM subjects had each rule explicitly stated in the memory set on different trials. In essence, CM subjects had to learn to respond positively to exemplars of "DXR 15-25" and negatively to exemplars of "DXR 25-35," even though the latter never explicitly appeared in the memory set. VM subjects also dealt with both of these rules, but had them explicitly presented in the memory set on different trials.

Design

Three major independent variables were included in the design: (a) target/distractor mapping, (b) memory set size, and (c) training sessions. Target/distractor mapping was either CM or VM, and represented a between-subjects variable. Eight subjects

were assigned to the CM group and eight subjects to the VM group. In the CM condition, one member of each pair of rules sharing a common letter designator served as targets throughout training for an individual subject. Negative exemplars were drawn from a designated set of exemplars which represented the alternate rule that shared the common letter designator. In the VM condition, exemplars of rules that shared a common letter designator served as both targets and distractors across blocks of trials. Memory set size was manipulated within blocks of trials in each group, and consisted of one to three sequences. Each group completed 16 sessions of practice trials across the 4 days of training.

Results

Reaction Time. Mean reaction time to test stimuli as a function of CM/VM condition and training sessions is illustrated in Figure 13. The means presented in Figure 13 are based on correct responses. As depicted in the figure, training sessions had an effect on reaction time in both stimulus mapping groups and it is clear that there was substantial improvement in reaction time in both groups. Beginning with Session 10, reaction times were consistently lower in the CM group than in the VM group, but improved as a function of training in both groups.

A 2-x-3-x-16 ANOVA was performed on the reaction time data to analyze the effects of mapping condition (CM versus VM), memory set size (1-3), and training session (1-16). Mapping condition was a between-subjects variable in this analysis, whereas memory set size and training session were within-subjects variables. This analysis indicated that the main effects of memory set size [$F(2,28) = 192.22$, $p < .001$], and training sessions [$F(15,210) = 79.98$, $p < .001$] were significant. The main effect of mapping condition [$F(1,14) = 0.07$, $p > .05$], however, failed to reach significance. In addition, the analysis showed that the interaction of CM/VM and memory set [$F(2,28) = 5.90$, $p < .01$], and the interaction of CM/VM with training sessions

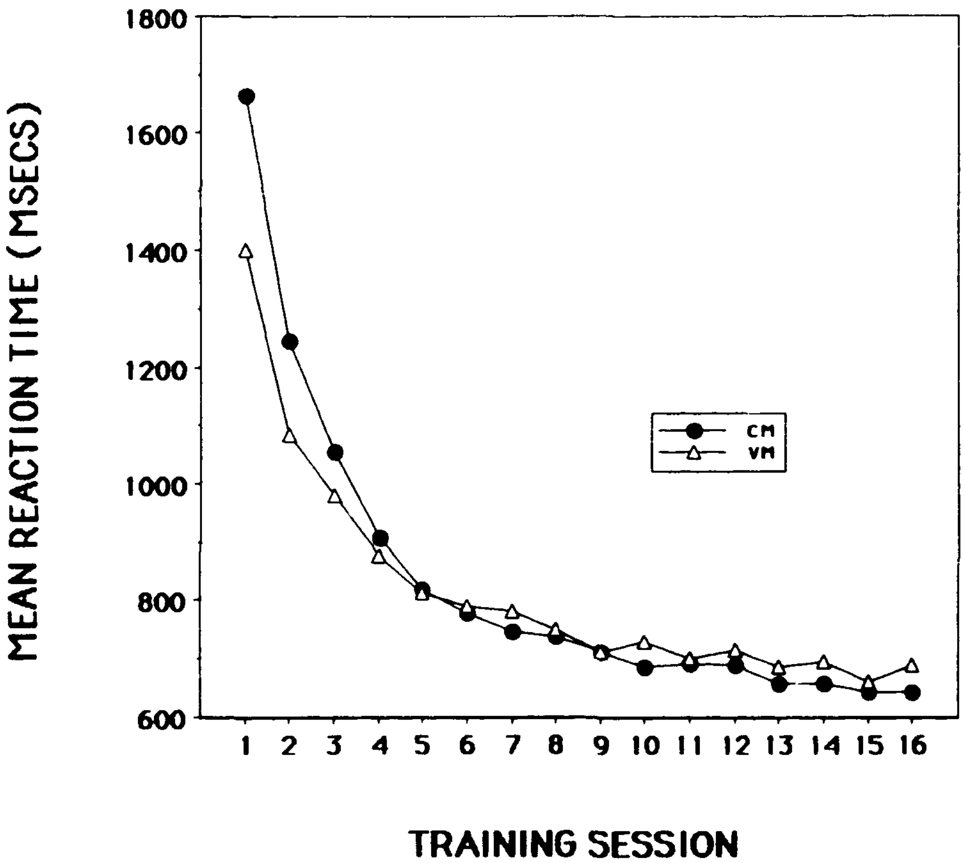

Figure 13. Mean Reaction Time as a Function of Mapping Condition and Training Session.

[$F(15,210) = 2.59$, $p < .01$] were also significant. All other interactions were not reliable.

To further investigate the significant CM/VM x sessions interaction, tests of simple main effects of CM vs VM were conducted at each training session. These analyses failed to demonstrate any significant effects of CM vs VM performance and suggest that the significant interaction is attributable to the pattern illustrated in Figure 13, in which CM reaction times tended to be initially higher than VM reaction times but became lower than VM times as training progressed. The tendency for CM performance to exceed VM performance over the final stages of training is illustrated in Figure 14, which shows mean CM and VM reaction times over the training sessions on the last day of practice. This figure not only illustrates the trend for CM reaction times to be superior to VM reaction times at the conclusion of training, but also demonstrates the relatively high level of variability associated with VM performance.

Tests of simple main effects of CM/VM were also conducted at each level of memory set size to investigate the significant CM/VM x memory-set interaction. These analyses also failed to demonstrate any reliable differences between mapping conditions. The significant CM/VM x memory-set interaction is apparently due to the trend for VM reaction times to be faster at memory set size one and CM reaction times to be faster at memory set size three. It should be noted that CM performance typically demonstrates its greatest advantage at higher memory set sizes within memory search paradigms (e.g. Eggemeier et al., 1990; Hale & Eggemeier, 1990; Fisk & Schneider, 1983), and this trend is therefore consistent with expectations concerning the effects of the mapping variable on reaction time.

In addition to reaction time differences between the CM and VM groups, a second criterion that can be applied to assess the development of automatic processing is a greater reduction in the

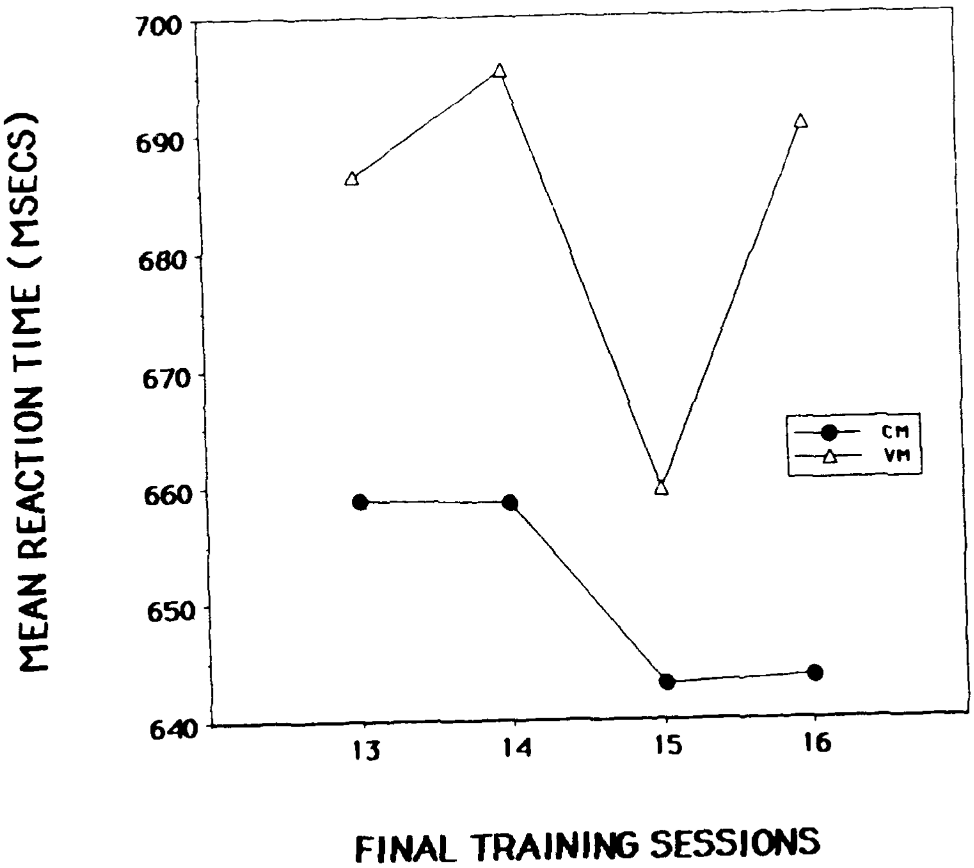

Figure 14. Mean Reaction Time as a Function of Mapping Condition and the Last Four Training Sessions.

effect of task demand within the CM group versus the VM group. Panel A of Figure 15 shows the effect of memory set size on reaction time in the CM and VM groups for the first session of training, and Panel B illustrates comparable functions for the last session of training. As is clear from the figure, memory set size had a substantial effect on both CM and VM performance during the first training session. At the conclusion of training, however, the effect of memory set on reaction time had been attenuated in the CM group, while memory set size continued to show a marked effect on VM group performance.

To characterize the effects of reductions in memory set size on performance in each group, slopes of the functions depicted in Figure 15 were computed. Within the CM group, the slope of the Session 1 function was 384.5 ms, and the slope of the Session 16 function was 91.5 ms. In the VM group, however, the slope of the Session 1 function was 411.5 ms, and was reduced to 170 ms by Session 16. At the conclusion of training, therefore, the slope of the VM function was almost two times larger than for the CM function. This type of CM-VM difference is consistent with the development of some level of automatic processing in the CM condition.

Figure 16 illustrates the mean standard deviation of reaction time as a function of mapping condition and training sessions. As can be seen in the figure, variability decreased in both CM and VM groups across training sessions. Also, after an initial disadvantage, the CM group tended to exhibit superior performance over the last sessions of training on this dimension as well.

A 2-x-3-x-16 ANOVA comparable to the mean reaction time analysis was performed on the data illustrated in Figure 16. The present analysis revealed that the main effects of memory set size [$F(2,28) = 96.85$, $p < .001$] and training sessions [$F(15,210) = 41.28$, $p < .001$] were significant. The main effect of mapping

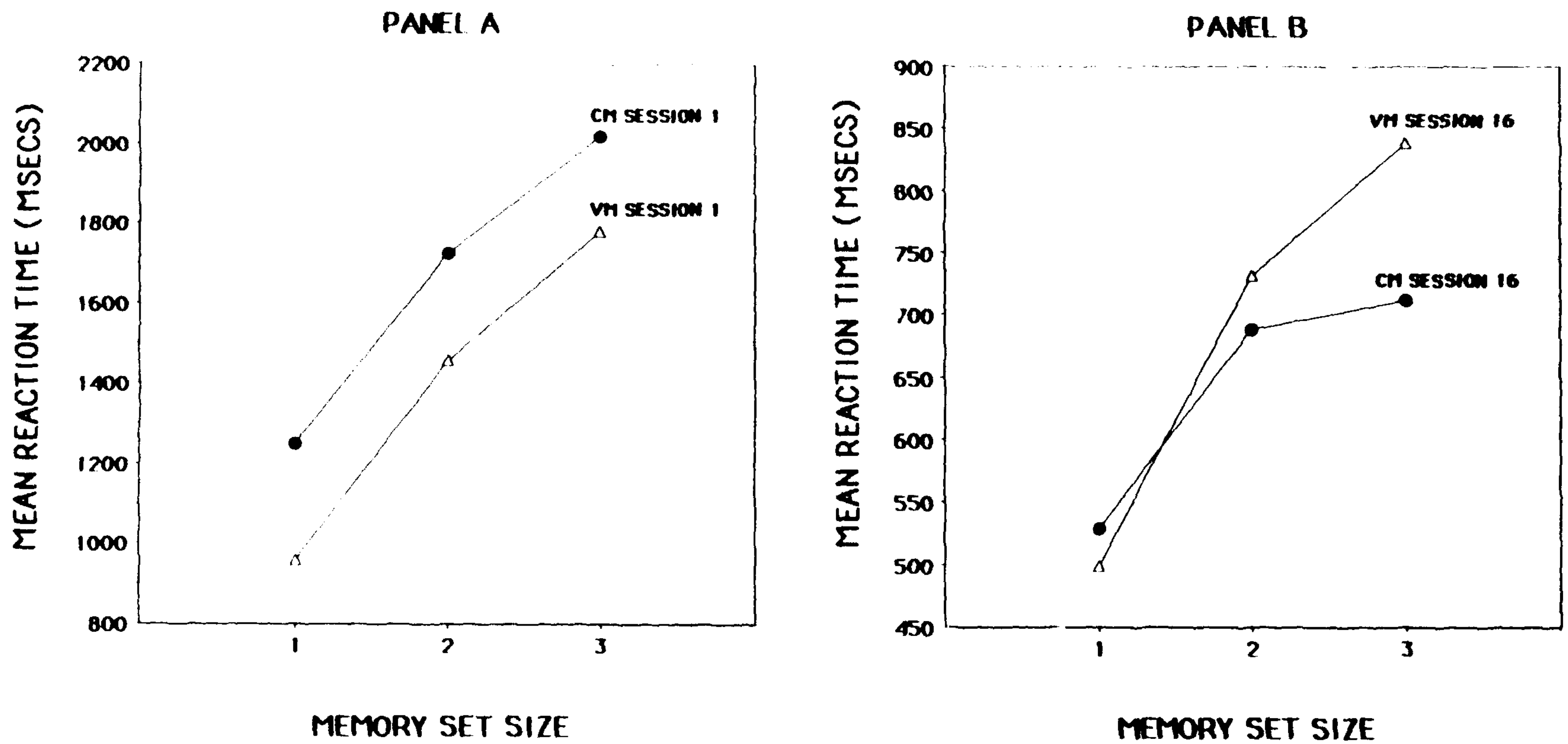

Figure 15. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Training Session.

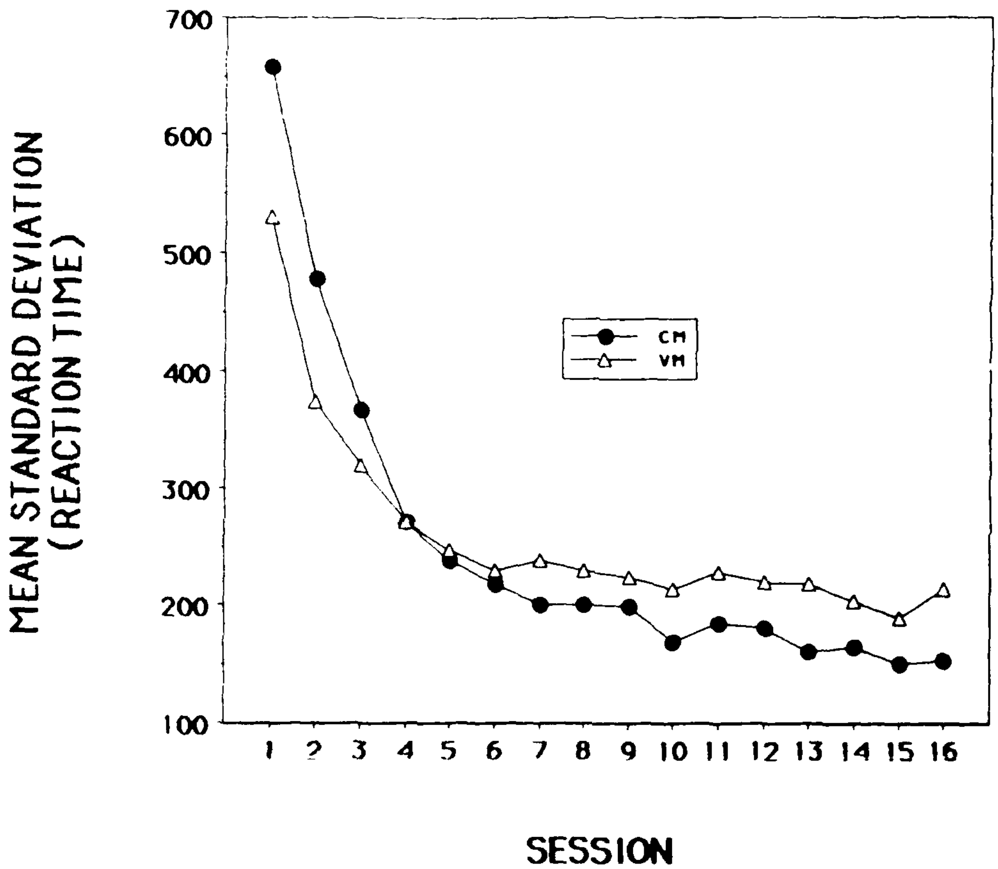

Figure 16. Mean Standard Deviation of Reaction Time as a Function of Mapping Condition and Training Session.

condition [$F(1,14) = 0.11$, $p > .05$] did not attain significance. In addition, the analysis demonstrated that the interaction of CM/VM and memory set [$F(2,28) = 9.94$, $p < .01$], the interaction of CM/VM with training sessions [$F(15,210) = 2.56$, $p < .01$], and the interaction of sessions and memory set [$F(30,420) = 4.28$, $p < .001$] were significant. The three-way interaction was not reliable.

The failure of the CM/VM main effect to reach significance indicates that overall, the mapping condition variable failed to reliably affect reaction times over the training sessions included in this experiment. However, the noted trend for CM mean reaction times and variability to be lower than comparable VM times during the latter stages of training, and the differences in the effect of memory set size on performance at the conclusion of training, suggest that some characteristics of automatic performance were beginning to develop in the CM group at the conclusion of training. It should also be noted that with the number of subjects used and the levels of inter-subject variability associated with this relatively complex task, the power associated with tests of between-subjects CM-VM treatment effects was very low (0.05). Therefore, the capability to detect overall CM-VM differences was quite restricted in the present experiment.

Accuracy of Responding. Figure 17 shows mean percent correct responses as a function of CM/VM group and training session. As is clear from the figure, response accuracy was consistently high and approximated the 90% criterion level required of the subjects.

A 2-x-3-x-16 ANOVA comparable to that performed on the reaction time data was conducted on the percent correct responses. This analysis demonstrated no main effect of mapping condition [$F(1,14) = 0.88$, $p > .05$]; a significant main effect of memory set size [$F(2,28) = 27.81$, $p < .001$]; and a reliable effect

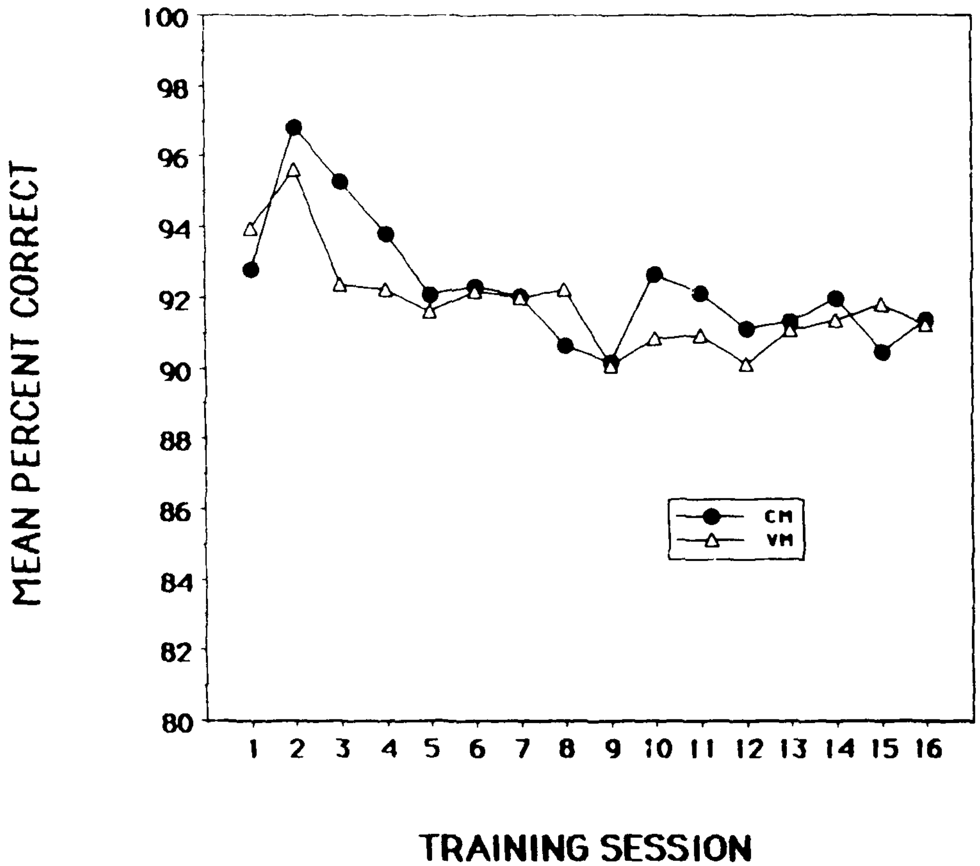

Figure 17. Mean Percent Correct as a Function of Mapping Condition and Training Session.

of training sessions [$F(15,210) = 7.02$, $p < .001$]. The CM/VM-x-memory-set-x-sessions interaction [$F(30,420) = 1.43$, $p < .07$] approached significance, but no other interactions were reliable.

The analysis of accuracy data therefore reflects the fact that subjects in both the CM and VM conditions maintained response accuracies that were very close to the criterion of 90% correct performance set at the beginning of the experiment. Performance in both conditions first improved and then tended to decline to more closely approximate the 90% criterion level as training sessions progressed. Feedback at the conclusion of each trial block had emphasized that subjects should respond as quickly as possible while maintaining at least a 90% accuracy level, and the tendency to approximate these levels with training probably represents the effects of this feedback. From the standpoint of CM-VM performance differences, the accuracy results provide no basis to infer that a speed-accuracy tradeoff that might affect interpretation of the reaction time data was present during the experiment.

Discussion

Both CM and VM groups demonstrated substantial improvements in performance over training sessions in this experiment. As noted previously, the present rule task incorporates a number of levels of consistency, and the current VM group actually represented a hybrid condition in which consistency was present at the rule-exemplar association level but was absent at the level of target/distractor search. The CM condition incorporated consistency at both levels. Because of the consistency present in the hybrid VM condition, considerable learning was expected to occur in this condition, as well as in the CM condition. This proved to be the case.

The failure to demonstrate a main effect of CM-vs-VM performance indicates that in this instance, the additional

consistency present in the CM versus the VM conditions was not sufficient to demonstrate overall differences in performance between the groups. However, as was discussed above, CM performance was *superior* to VM performance during the latter stages of training, and indices such as the slope of the memory set-reaction time function suggested some characteristics of automatic processing had begun to develop at the conclusion of training.

It should be noted here that subjects that participated in this experiment subsequently participated in a transfer experiment, reported in the next section. Two sessions of pre-transfer training were incorporated into the subsequent experiment, and stronger evidence of automatic processing than was present here was obtained during that additional training. This suggests that a task as complex as the current one that also incorporates consistencies at different levels may require more training than the 3,200 acquisition trials provided here to demonstrate reliable differences between a CM condition and a hybrid VM condition.

General Discussion

The results of Experiments 1 and 3 support the capability of subjects to develop some degree of automatic processing in tasks which involve the processing of spatial information of the type required in Air Force C2 systems.

Experiment 1 demonstrated differences in CM and VM performance that were consistent with the development of automaticity in the CM condition. Mean reaction time in the CM condition was consistently lower than in the VM condition, and CM performance was less affected by memory load than was VM performance at the conclusion of training. The results of Experiment 1 are therefore consistent with the earlier work of Eggemeier et al. (1990), and indicate that category membership is

not a limiting factor in the development of automatic processing with static spatial patterns over the levels of training used here.

As noted previously, Eggemeier et al. (1990) have demonstrated that the discriminability of target and distractor sets is a factor in the rate of development of characteristics of automatic processing with alphanumeric materials. It was expected that the discriminability of target and distractor sets in the current study would be reduced relative to the levels present in the earlier work of Eggemeier et al. (1990) that employed categorized target and distractor sets. Therefore, the reduced discriminability associated with the current target and distractor sets might have been expected to have a substantial impact on CM-vs-VM performance differences. Also, Eberts and Schneider (1986) have discussed difficulties with discriminability as a potential factor in their failure to obtain strong evidence of automatic processing with dynamic spatial patterns. The present results, however, indicate that the reductions in discriminability in the current experiment relative to the earlier categorized spatial pattern work did not preclude the development of automatic processing over the same number of training trials as used in the earlier study. This information is of potential importance to C2 operator training applications because, as noted above, differences in category membership and associated high levels of discriminability between target and distractor patterns cannot be guaranteed in actual C2 systems.

Evidence of automatic processing was also demonstrated in Experiment 3, which dealt with dynamic spatial pattern information similar to the type of spatial patterns that must be processed by C2 operators. CM performance in this experiment was more rapid than VM performance, and also demonstrated the reduction in the effect of memory set size on performance that characterizes automatic processing in a memory search task. The results of Experiment 3 are significant, because they demonstrate

that characteristics of automatic processing can be developed under the memory search conditions employed. This in turn indicates that the failure to demonstrate reliable CM-VM differences in Experiment 2 and in the previous work reported by Lawless and Eggemeier (1990) does not reflect a general limit on the capability of subjects to develop automatic processing with dynamic spatial pattern information.

As noted previously, there are a number of differences in procedure between Experiments 2 and 3 that could potentially account for the differences in results. These differences include the reduced display search and response requirements associated with Experiment 3. Also, both Experiment 2 and the Lawless and Eggemeier (1990) study utilized a pure display search paradigm while Experiment 3 used a combined memory/display search paradigm. This latter difference may prove to be of particular importance, and future research should therefore examine the effect of training on performance under VM and CM conditions in a pure visual search variant of the paradigm used in Experiment 3. This research would provide some information concerning whether visual vs memory search represents a limiting factor in the development of automatic processing with the types of patterns used in Experiment 3. This information would also be of potential relevance to C2 training applications, because many of the functions performed by C2 operators are of a visual search nature.

Finally, although differences in CM and VM performance were demonstrated at the conclusion of training in Experiment 4, the results failed to produce reliable evidence of automatic processing in the complex rule-based alphanumeric task investigated. As discussed previously, the VM condition in this task was actually a hybrid condition that included consistency at one level of the task and inconsistency at another level. Because automatic processing theory maintains that the consistent elements of task profit from training, it was anticipated that

considerable learning would occur in the hybrid condition, and this effect was in fact demonstrated.

It appears highly probable that significant CM-VM differences would have been obtained in this task with the inclusion of a pure VM condition that eliminated the exemplar-rule consistency present in the current paradigm. With the inclusion of this condition in an experiment, it is predicted that pure CM performance should be reliably better than pure VM performance, and that the current hybrid VM condition would result in performance levels that were at some intermediate point between the two pure mapping conditions. Future research should examine this prediction, and should also extend the current rule-based memory search work to a visual search task. Once again, such research would be of potential importance to C2 training applications, because many C2 operator tasks include a significant visual search component.

III. TRANSFER AND RETENTION OF AUTOMATIC PROCESSES IN TASKS REQUIRING THE PROCESSING OF COMPLEX SPATIAL PATTERN OR ALPHANUMERIC INFORMATION

Additional important issues that pertain to the application of an automatic-processing-based approach to C2 operator skill acquisition concern the transfer and retention of automatic processing that can be expected with the types of materials described above. Data concerning the conditions and limits of automatic component transfer and retention are very important for the design of training programs intended to support the development and maintenance of automatic processing with these components.

Transfer of Training

Information concerning transfer of training is critical, for example, to support the development of efficient training programs designed to establish automatic processing in consistent components of operator tasks. One important issue relevant to the rule-based search task described in the previous section concerns the transfer that can be expected to untrained exemplars of the alphanumeric rules that make up the search set. Because establishment of automatic processing in a complex task such as alphanumeric rule search can require thousands of acquisition trials, important economies could be realized in training programs if only a limited subset of rule exemplars needed to be trained. This type of limited training approach could be undertaken if it could be expected that there would be positive transfer to untrained exemplars of the trained rules.

Several previous experiments (e.g., Hale & Eggemeier, 1990; Hassoun & Eggemeier, 1988; Schneider & Fisk, 1984) have demonstrated transfer of automatic processing with semantic materials that are important to operator performance in complex systems. For example, Hale and Eggemeier (1990) studied transfer of automatic processing to untrained exemplars of previously trained semantic categories in a category memory search paradigm. In the Hale and Eggemeier (1990) experiment, the memory set consisted of semantic category names (e.g., "Vegetables," "Professions"), and subjects decided if a subsequently presented item (e.g., "Lawyer") was an exemplar of a memory-set category. After extensive CM training with a subset of category exemplars, subjects were transferred to one of three semantic search conditions: (a) Same Semantic Categories/Same Exemplars (S/S), (b) Same Semantic Categories/Different Exemplars (S/D), or (c) Different Semantic Categories/Different Exemplars (D/D). At transfer, the S/D group demonstrated significantly faster reaction times than those of the D/D control group, indicating

the presence of positive transfer to untrained subsets of exemplars of the trained categories.

Similar results have been reported in a visual search variant of the semantic category paradigm (Schneider & Fisk, 1984), and in a word search paradigm under high memory load conditions (Hassoun & Eggemeier, 1988). The results of these experiments are significant because they demonstrate positive transfer of automatic processing with a semantic category search task that is conceptually similar to the rule-based alphanumeric search task performed by operators of some C2 systems.

A second transfer-of-training issue critical to the design of training programs to support the development of automatic processing in subcomponents of C2 operator tasks concerns the transfer that can be expected from less complex or lower workload variants of tasks that must be trained to more complex or higher workload versions of the same tasks. The importance of providing initial training under lower workload versions of tasks is based on the expectation that the development of automatic processing is dependent upon the availability of sufficient controlled processing resources, and that high workload training conditions can therefore impair skill acquisition. Nissen & Bullemer (1984), for example, have presented evidence which indicates that acquisition of a serial reaction time task was impaired when subjects were trained under dual-task as opposed to single-task conditions. Because some variants of C2 operator functions such as the previously described weather pattern search task can impose high levels of workload on the operator, considerable utility might be realized through initial training to establish some level of automatic processing on lower workload variants of a task, and then transferring to higher workload versions of the same task. Therefore, data concerning the transfer of both CM and VM performance from lower to higher workload variants of analogs of C2 operator tasks are of considerable importance to training program development.

Retention of Automatic Processing

In addition to transfer of training, information concerning the retention functions associated with automatic processes is essential for efficient structuring of training programs designed to permit not only the initial acquisition of automatic processing, but also the maintenance of this processing over extended time periods. The issue of retention of automatic processing has not been widely researched, and the automatic processing literature contains only a limited number of studies that bear on retention. Shiffrin and Dumais (1981), for instance, discussed the results of an unpublished study by Dumais, Foyle, and Shiffrin in which retention of automatic processing in visual search tasks was investigated. Retention intervals of 1.4, 2.7, and 7.2 weeks were used, and CM performance proved superior to VM performance at all retention intervals. Some forgetting did, however, occur at 2.7 and 7.2 weeks subsequent to training.

In a more recent investigation, Fisk et al. (1990) studied the retention of automatic processing in a semantic category search task over retention intervals of 1, 30, 60, 90, and 180 days. The paradigm used in this experiment was a hybrid visual/memory search task that required subjects to identify an exemplar of previously presented semantic categories from among three test items. The results indicated that some forgetting did occur at the 30-day retention interval, but also demonstrated that no additional reliable decrements in performance occurred at the 60-, 90-, and 180-day retention intervals. The Fisk et al. results therefore suggest that the bulk of forgetting over a 6-month retention interval occurs during the first 30 days in a semantic category visual/memory search task. Subsequent experiments examined retention in both a pure visual search version of the semantic category task and a pure memory search version of the task. The results of these experiments indicated that though some forgetting occurred during a 30-day retention

interval in the visual search task, no reliable evidence of forgetting occurred in the memory search version of the task.

The results of the Dumais et al. and Fisk et al. experiments indicate that some forgetting of automatic processing can occur over periods of disuse, and the results of the Fisk et al. investigations further suggest that the bulk of this forgetting occurs during the first 30 days of a 6-month interval. Extension of these previous results to other types of information that must be processed by operators of C2 systems is critical for applications of an automatic-processing-based approach to operator training, because the resulting data could have important implications for maintenance of automatic processing with such materials.

Overview of Present Studies

Although there have been several demonstrations of positive transfer of automatic processing within semantic category search paradigms, issues pertaining to transfer of the type of complex alphanumeric rule task investigated in Experiment 4 have not been researched. Likewise, the issue of transfer of CM and VM training from a low workload to a higher workload variant of the complex weather pattern search task investigated in Experiment 2 has not been addressed in the automatic processing literature. Therefore, Experiments 5 and 6 were conducted to investigate transfer of CM and VM training in the rule-based alphanumeric memory search task and in the weather pattern detection task, respectively.

It was also considered important to extend the Fisk et al. research on retention of automatic processing with semantic materials to the type of spatial pattern information examined in Experiment 1. The semantic information used in the Fisk et al. (1990) work took advantage of categorization schemes that were well organized for subjects prior to search task training, and it appeared possible that different retention characteristics might

be associated with spatial pattern information that was unfamiliar to subjects at the beginning of training. Therefore, Experiment 7 examined the retention of CM and VM training with spatial pattern information of the type investigated in Experiment 1.

Experiment 5
Transfer of Training with Complex Alphanumeric Materials in a Rule-Based Search Task

Purpose

The purpose of this experiment was to investigate transfer of CM and VM training to untrained exemplars of previously trained rules in the complex alphanumeric memory search task investigated in Experiment 4. As noted above, the issue of transfer from a limited subset of the exemplars/non-exemplars associated with a particular rule has significant practical implications for the design of training programs. It is also of theoretical importance because positive transfer to untrained exemplars of a rule would indicate that the learning that had taken place during acquisition trials was at the rule level rather than at the level of individual exemplars. Therefore, this experiment was conducted to determine the level of performance that would result when subjects trained under CM and VM conditions in the complex alphanumeric rule task of Experiment 4 were transferred to untrained exemplars of trained rules. A control condition in which subjects were transferred to a task that involved the processing of completely different rules and exemplar sets was also included.

As noted above, a number of investigators (e.g., Hale & Eggemeier, 1990; Hassoun & Eggemeier, 1988; Schneider & Fisk, 1984) have demonstrated positive transfer to untrained exemplars of trained semantic categories under CM conditions. It was therefore anticipated that positive transfer might also be

demonstrated relative to the different rule control in the present task under CM training conditions. Hale and Eggemeier (1990), however, have shown that no such transfer occurs under VM conditions. Based on the latter results, no substantial differences between the two transfer conditions under VM training were expected.

Method

Subjects. Subjects were the same 16 University of Dayton students who had participated in Experiment 4. They were paid $5.00 per hour for their participation.

Apparatus. The experiment used the same type of Zenith Data Systems 248 computer and Zenith ZCM-1490 high-resolution color monitor used in Experiment 4. Responses were made on the same arrow keys of a standard expanded IBM-compatible keyboard as used previously.

Procedure. Subjects performed the same type of memory search task performed in Experiment 4. The same target/distractor mapping (CM vs VM) that a subject had been trained on in Experiment 4 was maintained for that subject throughout this experiment. On each trial, subjects were presented with a memory set of three alphanumeric rules that remained on the CRT screen until the subject pressed a designated key. These rules were the same type used in Experiment 4, and consisted of the conjunction of a three-letter sequence and a range of numerical values. After presentation of the memory set, a fixation cross appeared in the middle of the screen for 500 ms. This cross was replaced by a single test item displayed for a maximum of 2 seconds or until the subject responded. Test items were the same type as used in Experiment 4, and consisted of a three-letter sequence and a single two-digit numeral.

Subjects determined if the test item represented an exemplar of the rules presented in the memory set, and responded "yes" or "no" by pressing a labeled response button on the keyboard. One-half of the target items in each block of trials were members of the memory set. Both reaction time and accuracy measures were collected. The same 90% criterion level used in Experiment 4 was maintained in this experiment.

Visual feedback was provided to subjects in the same format as in Experiment 4. After each trial, an incorrect response was followed by a "Wrong Response" message. A correct response was followed by a "Correct Response" message and the reaction time for that trial.

Summary feedback was provided at the completion of each block of trials. This feedback provided mean reaction time and accuracy performance levels from the trial block just completed. In addition to feedback at the completion of a block, summary feedback concerning mean reaction times and accuracy levels was provided to subjects at the completion of each session. A written tally of mean reaction time and accuracy levels across sessions was made available to subjects as an aid in monitoring progress across sessions.

The experiment was divided into two phases: (a) pre-transfer and (b) transfer. The purpose of the pre-transfer phase was to establish a performance baseline that could be used to assess levels of transfer in the subsequent phase, and to provide practice to the subjects in performance of the search task under only the memory set size three condition. Memory sets of three rules were used in this experiment to increase the potential to detect any transfer differences which might be present.

Subjects completed two sessions of pre-transfer performance on the day following the completion of Experiment 4. Each pre-transfer session included 10 blocks of 20 trials each, for a

total of 400 pre-transfer trials. Memory set size was held constant at three alphanumeric rules. Pre-transfer sessions used the same memory set rules and the same target and distractor sets that had been used to train each individual subject in Experiment 4. Two CM subjects therefore continued with alphanumeric rules drawn from rule set "A" and with exemplars and non-exemplars of those rules that used odd numerical values. Likewise, two additional CM subjects continued with rules drawn from set "A" and with even exemplars/non-exemplars. Two other CM subjects continued with rules from set "B" with even exemplars/non-exemplars, while the remaining two CM subjects continued with set "B" rules and odd exemplars/non-exemplars. The eight subjects in the VM condition were divided into the same rule/exemplar combinations as the CM subjects, and continued with either rule sets "A" or "B" and with either odd or even exemplars/non-exemplars as appropriate.

After completion of pre-transfer, all subjects were transferred to one of two conditions: (a) the Same rules but with Different exemplars (S/D) than had been previously trained, or (b) Different rules and Different exemplars (D/D) than had been previously trained. The first letter group designation indicates if the alphanumeric rule used at transfer was the same or different from pre-transfer, and the second designation indicates if the exemplar/non-exemplar sets were the same as or different from pre-transfer. Rule changes consisted of changes in both the letter sequences that stood for system parameter designators and the numerical values associated with the parameters. Exemplar changes involved a change in the values associated with a rule, such that subjects trained with even-valued numerical exemplars were changed to odd-valued exemplars, and vice-versa. D/D conditions therefore involved a change in the letter designators, the associated range of numerical values, and the type of exemplars (even vs odd) presented to subjects. S/D conditions, on the other hand, permitted subjects to continue with the same letter designators and range of associated numerical values that

had been used in pre-transfer, and involved only a change in the type of exemplars (even vs odd) that were presented at transfer.

There were four CM subjects and four VM subjects assigned to each transfer group, and each transfer group included a representative of each unique combination of rule set and exemplar type used during pre-transfer.

The transfer phase for all subjects consisted of two sessions of 10 blocks with 20 trials each, for a total of 400 trials.

Design. Three independent variables were included in the design: (a) mapping condition (CM vs VM), (b) sessions of pre-transfer or transfer trials, and (b) transfer group (S/D, D/D).

Results

Pre-transfer and transfer data were analyzed separately. In each case, correct responses in sessions of 200 trials were used in the data analyses.

Pre-Transfer Reaction Time. Figure 18 shows mean reaction time as a function of mapping condition and transfer group across the two sessions of pre-transfer. As is shown in the figure, transfer group did not have a major effect on mean reaction time in either mapping condition, but there was a trend for the CM group to exhibit faster reaction times than those associated with the VM group across the pre-transfer sessions. CM-VM differences averaged 137 ms in Session 1 and 114 ms in Session 2.

A 2-x-2-x-2 ANOVA was conducted on these data to investigate the effects of mapping condition (CM vs VM), pre-transfer sessions, and transfer group (S/D vs D/D) on reaction time performance. This analysis indicated that neither the main effect of transfer group [$F(1,12) = 0.02$, $p > .85$] nor the main effect of

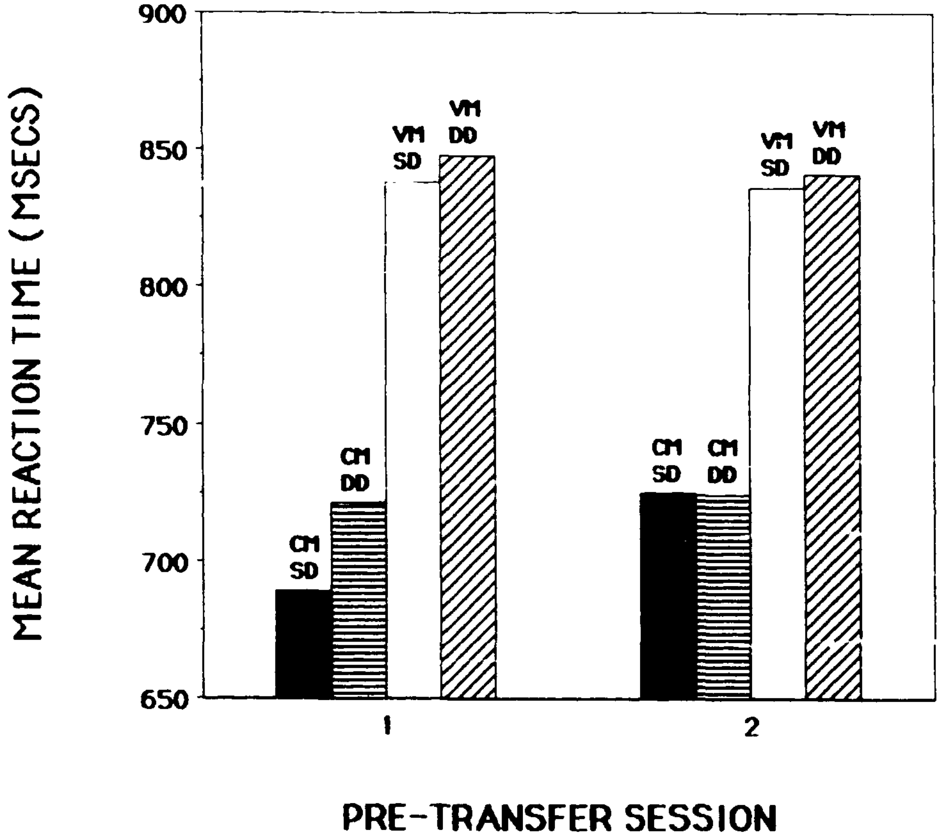

Figure 18. Mean Reaction Time as a Function of Mapping Condition, Transfer Group, and Pre-Transfer Session.

pre-transfer sessions [$F(1,12) = 0.76$, $p > .75$] was significant. None of the interactions proved reliable. The main effect of mapping condition [$F(1,12) = 2.58$, $p < .15$] was not significant, indicating that the trend noted above for CM performance to be more rapid than VM performance was not statistically reliable. The trend is important, however, because it suggests a tendency for CM-VM differences to emerge in this task with memory set sizes of three. As explained earlier, CM-VM differences tend to more pronounced under higher memory set sizes, and the noted trend in the pre-transfer data suggests that some level of automatic processing may have begun to develop in the CM group at the time of pre-transfer performance sessions.

In addition to analyses of the mean reaction time data, analyses were also conducted on the mean standard deviation of reaction times to determine if there were significant differences associated with response variability as a function of mapping condition, transfer group, or pre-transfer sessions. As previously indicated, automatic processing tends to be associated with less variability in performance than does controlled processing.

Figure 19 shows mean standard deviation of reaction time as a function of mapping condition, pre-transfer sessions, and transfer group. As is clear from the figure, mapping condition had a substantial effect on variability, with the CM condition demonstrating less variable performance than the VM condition across both sessions of pre-transfer. The mean standard deviation across pre-transfer sessions was 173 ms in the CM group, compared to a mean of 260 ms in the VM group.

A 2-x-2-x-2 ANOVA comparable to that conducted on the mean reaction time data was performed on the standard deviation data to investigate the effects of mapping condition (CM vs VM), pre-transfer sessions, and transfer group (S/D vs D/D) on performance. This analysis demonstrated that the main effect of

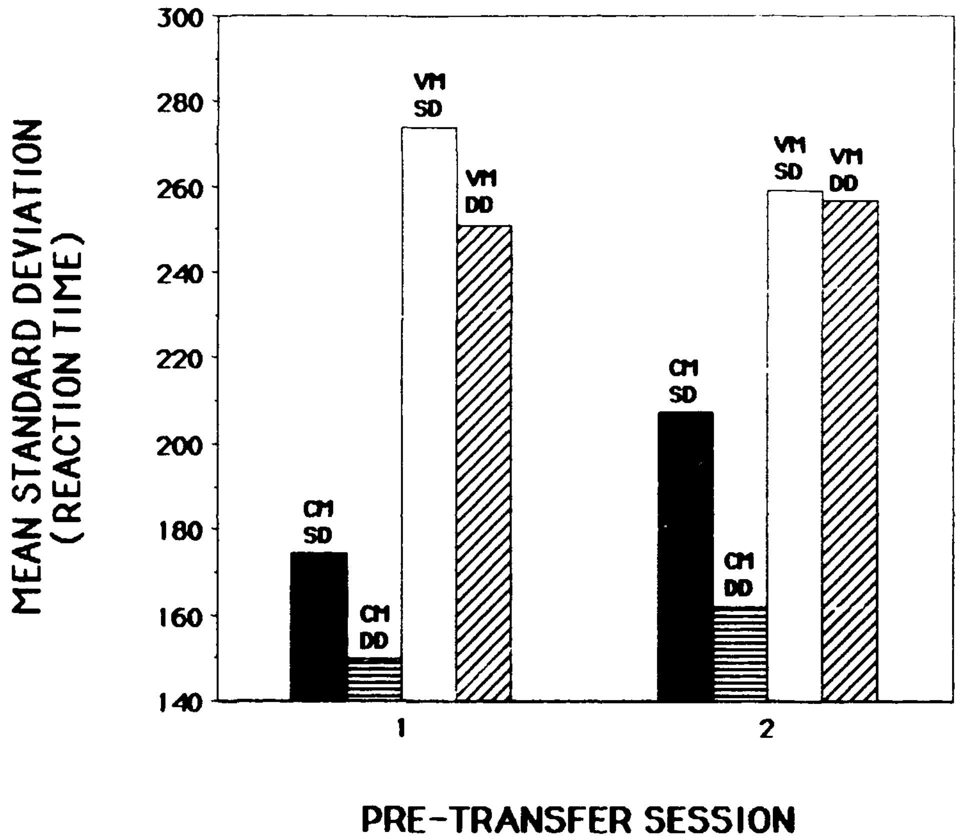

Figure 19. Mean Standard Deviation of Reaction Time as a Function of Mapping Condition, Transfer Group, and Pre-Transfer Session.

mapping condition [$F(1,12) = 8.17$, $p < .02$] was significant, but showed that neither the main effect of transfer group [$F(1,12) = 0.61$, $p > .45$] nor the main effect of pre-transfer sessions [$F(1,12) = 1.12$, $p > .30$] was significant. None of the interactions were reliable.

The results of this analysis therefore indicate that during pre-transfer, CM reaction time performance was less variable than comparable VM performance. This difference in variability is consistent with the development of automatic processing in the rule-based task within the CM group, and provides additional evidence to suggest that some level of such processing had developed at the time of the pre-transfer training sessions.

Pre-Transfer Response Accuracy. Figure 20 shows mean percent correct as a function of mapping condition, transfer group, and pre-transfer sessions. As illustrated in the figure, neither transfer group nor mapping condition had an appreciable effect on accuracy. Accuracy of responding was consistently high and, in all conditions, approximated the 90% criterion established for subjects.

A 2-x-2-x-2 ANOVA was conducted on the percent correct data to investigate the effects of mapping condition, pre-transfer sessions, and transfer group on percent correct performance. This analysis indicated that neither the main effect of mapping condition [$F(1,12)= 0.40$, $p > .50$], the effect of transfer group [$F(1,12) = 1.45$, $p > .25$], nor the effect of pre-transfer sessions [$F(1,12) = 0.21$, $p > .65$] was reliable. None of the interactions proved significant.

The absence of any significant effect involving transfer groups in both analyses indicates that there were no significant differences in the accuracy of performance between the groups at the conclusion of training, thereby facilitating interpretation of any transfer differences.

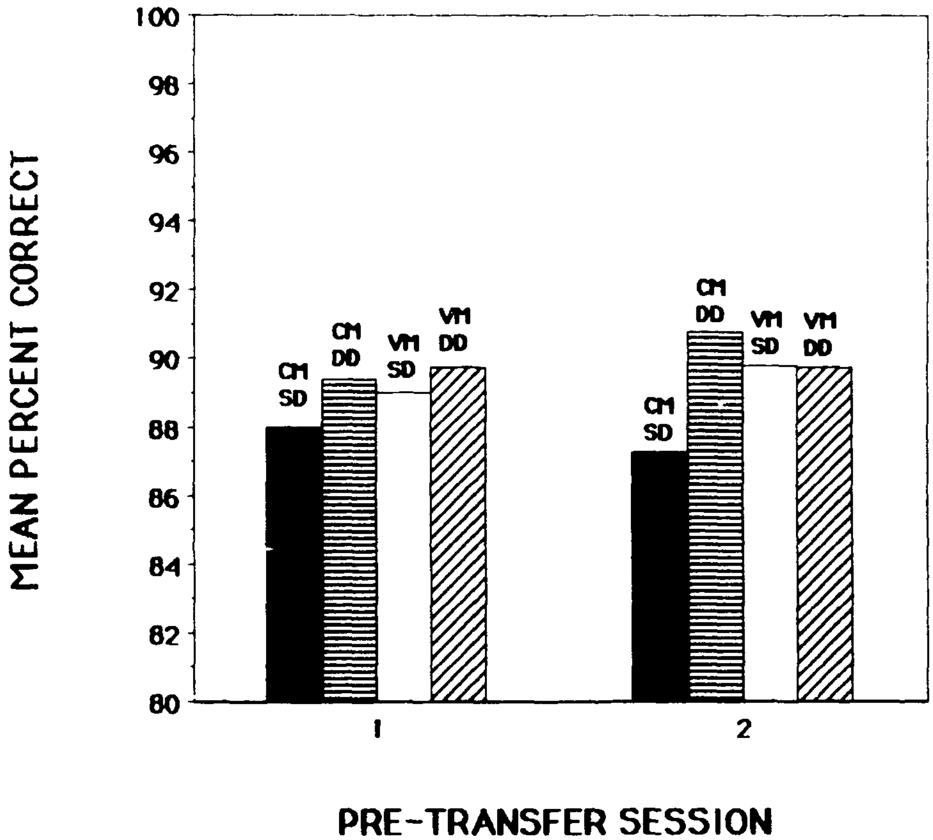

Figure 20. Mean Percent Correct as a Function of Mapping Condition, Transfer Group, and Pre-Transfer Session.

Transfer Reaction Time. Figure 21 shows mean reaction time as a function of mapping condition, transfer condition, and transfer sessions. As illustrated in the figure, the S/D vs D/D transfer conditions appear to have had a differential effect on performance within the CM condition, but had little effect on performance within the VM condition. The figure also shows that CM performance in the D/D condition was markedly disrupted relative to other conditions in Session 1, but had begun to approximate VM performance levels during Session 2.

Relative to pre-transfer baselines there was negative transfer in all conditions. This result is consistent with previous experiments (e.g., Hale & Eggemeier, 1990; Hassoun & Eggemeier, 1988) and was therefore expected. Using the last pre-transfer session as a baseline, the CM-SD condition showed a mean decrement of 31 ms versus a 265-ms decrement in the CM-DD condition. Comparable decrements in the VM condition were 97 ms and 56 ms in the S/D and D/D conditions, respectively.

A 2-x-2-x-2 ANOVA was performed on the reaction time data shown in Figure 21. The purpose of this analysis was to investigate S/D vs D/D differences as a function of mapping condition and transfer session. The ANOVA showed that the effect of CM/VM mapping condition [$F(1,12) = .10$, $p > .05$] was not significant, but showed a significant effect of transfer sessions [$F(1,12) = 8.21$, $p < .02$] and a marginal effect of S/D vs D/D transfer conditions [$F(1,12) = 4.13$, $p < .07$]. The analysis also demonstrated that the SD/DD x sessions interaction [$F(1,12) = 4.84$, $p < .05$] was significant, and that the CM/VM x SD/DD interaction [$F(1,12) = 4.02$, $p < .07$] and CM/VM x sessions interaction [$F(1,12) = 4.31$, $p < .06$] approached significance. The three-way interaction was not reliable.

A difference score analysis performed on the data showed the same results. Difference scores were computed by subtracting the mean reaction time of each subject during the last session of

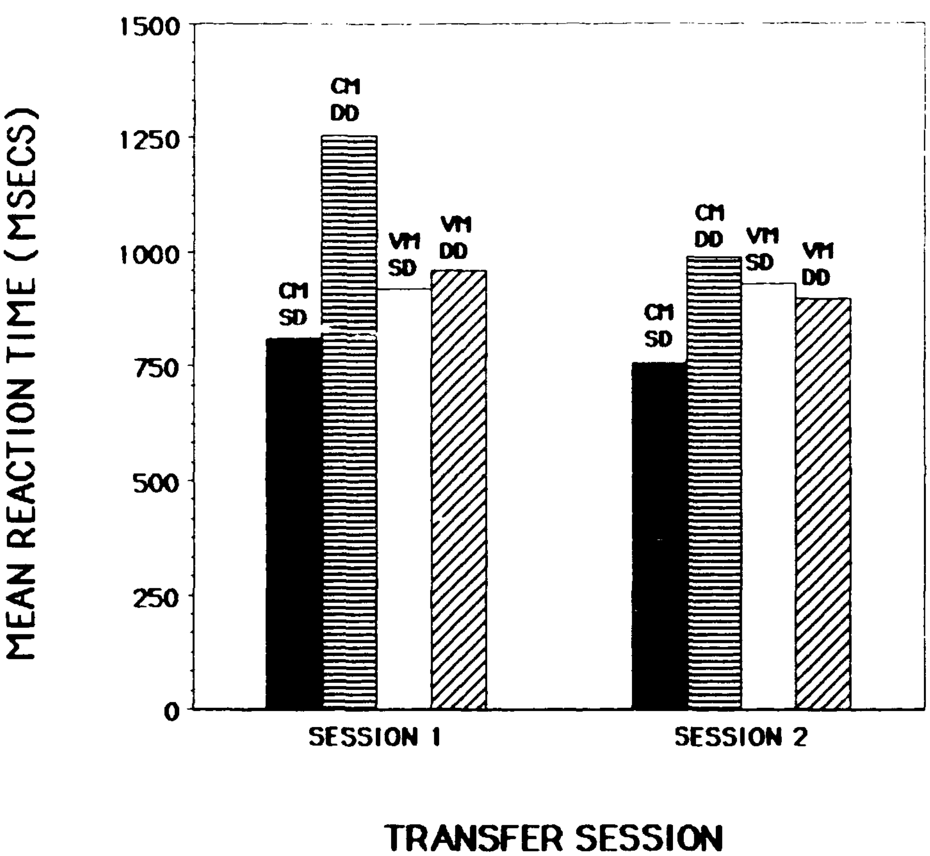

Figure 21. Mean Reaction Time as a Function of Mapping Condition, Transfer Condition, and Transfer Session.

pre-transfer from the mean reaction time of that subject during transfer Sessions 1 and 2, respectively. The resulting difference scores were then subjected to the same type of 2-x-2-x-2 ANOVA reported above. This analysis produced exactly the same pattern of results as described above.

The fact that the CM/VM x SD/DD interaction approached significance is noteworthy, because positive S/D transfer relative to D/D transfer under CM mapping would indicate that the benefits of any automatic processing established during training were applicable to untrained exemplars of trained rules. No differences in transfer condition were expected under VM conditions, because the inconsistency in application of the rules as target and distractors during training should have precluded substantial rule-response learning. The pattern of results shown in Figure 21 suggests a trend for CM-SD performance to exceed CM-DD performance, and this trend is consistent with expectations that would be associated with positive transfer to untrained exemplars in the CM condition.

Figure 22 shows the mean standard deviation of reaction time as a function of mapping condition, transfer group, and transfer session. The results parallel those of the mean reaction time data, and show a tendency for the S/D condition under CM mapping to demonstrate less variability than its D/D counterpart. Variability in both VM transfer conditions, on the other hand, was approximately the same. Once again, there was considerable disruption in the CM-DD condition relative to all other conditions in Session 1, but CM-DD variability had begun to approximate that of the other conditions by Session 2.

A 2-x-2-x-2 ANOVA that was comparable to the reaction time analysis was performed on the reaction time standard deviation data. This analysis produced no significant main effects nor interactions, although the main effect of sessions [$F(1,12) = 4.04$, $p < .07$], the sessions x CM/VM interaction [$F(1,12) = 3.99$,

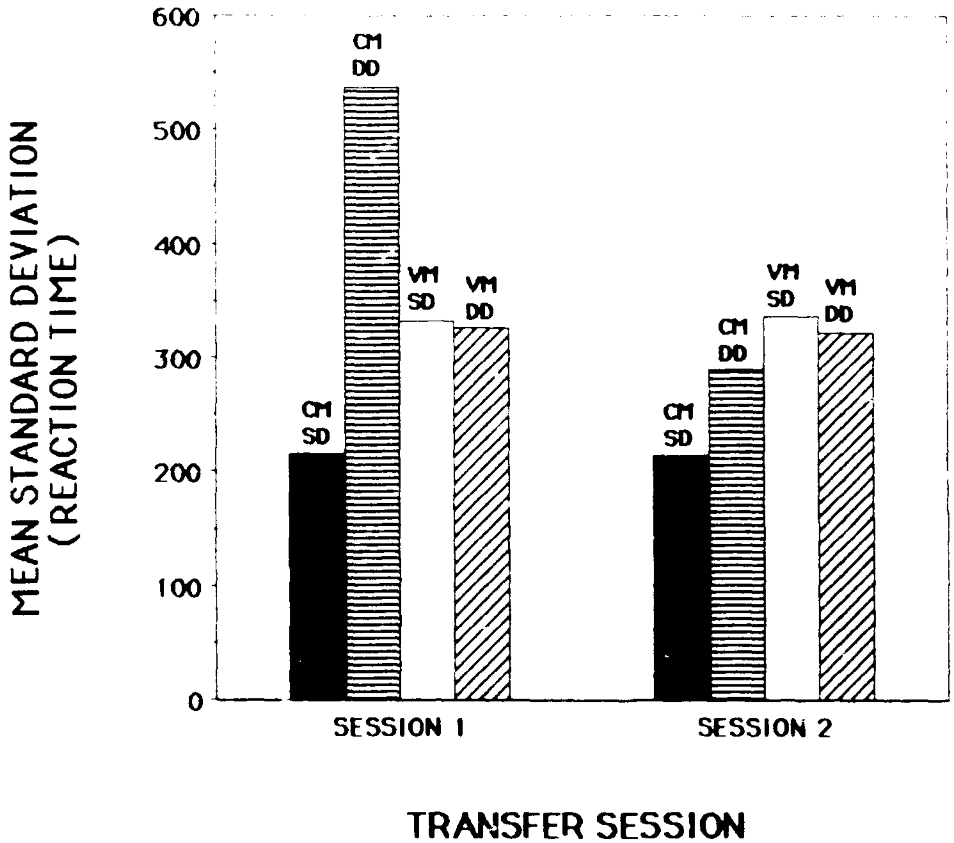

Figure 22. Mean Standard Deviation of Reaction Time as a Function of Mapping Condition, Transfer Group, and Transfer Session.

$p < .07$], the sessions x SD/DD interaction [$F(1,12) = 4.22$, $p < .07$], and the CM/VM x SD/DD x sessions interaction [$F(1,12) = 3.59$, $p < .08$] all approached significance. The overall reliable effect of mapping condition on the variability of performance was therefore not maintained at transfer. Because CM-SD variability was approximately the same at transfer as at pre-transfer, the loss of the effect is apparently due to the very high levels of variability demonstrated in the CM-DD condition.

Transfer Response Accuracy. The percent correct response data for the transfer sessions were also subjected to a 2-x-2-x-2 ANOVA. Mean percent correct responses as a function of mapping condition, transfer condition, and transfer sessions are shown in Figure 23. As is clear from the figure, accuracy of responding was consistently high across all conditions and transfer sessions. Performance in the CM conditions was initially lower than that in the VM condition, but approximated VM performance in Session 2.

The results of the ANOVA showed that there was neither a main effect of CM/VM mapping condition [$F(1,12) = .49$, $p > .05$] nor a main effect of S/D vs D/D transfer condition [$F(1,12) = 0.12$, $p > .05$]. The CM/VM x sessions interaction [$F(1,12) = 5.17$, $p < .05$] was significant, however, and the main effect of sessions [$F(1,12) = 4.37$, $p < .06$] approached significance. None of the other interactions were significant. The results of this analysis therefore indicate that the trend for CM improvement across sessions was reliable, and also showed no main effect or interaction involving transfer condition that would have suggested a speed-accuracy tradeoff.

Discussion

The results of the pre-transfer phase of this experiment demonstrated several trends that were consistent with the development of automatic processing in the complex alphanumeric

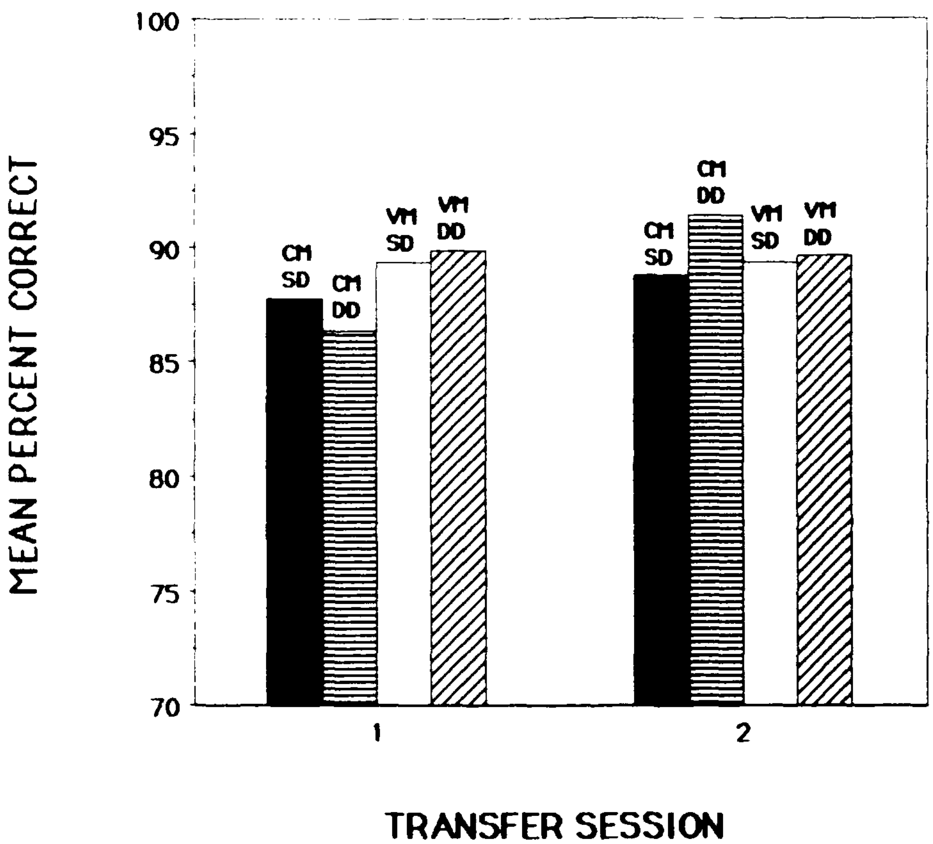

Figure 23. Mean Percent Correct as a Function of Mapping Condition, Transfer Group, and Transfer Session.

rule-based task investigated. These included a consistent but non-significant reaction time advantage for the CM group relative to the VM group, and a significantly lower level of reaction time variability under CM as opposed to VM conditions.

The general pattern of transfer performance was consistent with expectations, and suggests a trend for positive transfer in the S/D condition relative to the D/D condition under CM training when the speed of response is considered. Positive S/D transfer only in the CM condition is consistent with expectations in this experiment, as it was only the CM subjects who could consistently respond to a particular rule. On the basis of previous results (e.g., Hale & Eggemeier, 1990), no positive transfer was expected in the VM-SD condition relative to the VM-DD condition, and the general pattern of the results is also consistent with these expectations.

Interpretation of S/D vs D/D reaction time differences is somewhat clouded by the relatively high level of disruption of performance evidenced in the CM D/D condition at Session 1, but the same pattern of S/D superiority continued to be exhibited in Session 2 when CM-DD performance had returned to VM performance levels.

Positive transfer to S/D conditions in the semantic category search tasks used by Hale and Eggemeier (1990) and Hassoun and Eggemeier (1988) tended to be relatively short-lived, due to the rapid improvement in the D/D control condition demonstrated in both previous studies. With the complex rule-based task used here, D/D improvement appears to be less rapid. The potential benefits associated with S/D transfer in this type of task may be more enduring and ultimately of greater practical significance than with the type of semantic category task researched by Hale and Eggemeier (1990) and Hassoun and Eggemeier (1988). Future research that examines transfer in this type of task should

include a greater number of transfer sessions than used here, to more fully explore this possibility.

Experiment 6
Transfer of CM and VM Training in a Complex Weather Pattern Search Task

Purpose

The purpose of this experiment was to determine if any CM-VM performance differences established during Experiment 2 would be maintained when subjects were transferred to a higher workload version of the same weather pattern detection task. The workload manipulation used in this experiment was the level of visual background noise present on the simulated weather satellite system display. As described earlier, subjects who participated in Experiment 2 had searched for walking-dot weather patterns on a map of Ohio display that contained no visual background noise. Assuming that CM-VM performance differences would be demonstrated under the lower workload condition, an important issue that bears on the feasibility of using lower workload tasks to train operators to perform in a higher workload environment concerns the capability of subjects to maintain those CM-VM differences under higher workload conditions. This experiment was therefore designed to provide initial information concerning the transfer of CM and VM performance levels from a condition of no background noise to a relatively low level of such noise in the weather pattern search task.

Method

Subjects. Subjects were the same 12 University of Dayton students who had participated in Experiment 2. They were paid $4.00 per hour for their participation. A $1.00 an hour bonus was also paid to those subjects who arrived on schedule for each of the transfer sessions.

Apparatus. This experiment used the same Macintosh IIx computers with extended keyboards and mouse interfaces used in Experiment 2 to simulate a weather satellite display. The computers presented the stimuli, recorded subject responses, and controlled the experiment. A high-resolution, 19-inch PCPC color monitor presented the target and distractor stimuli. Subjects used the standard mouse with a single button to superimpose a cursor on a target stimulus, and activated the button to indicate the selection of the target pattern superimposed by the cursor.

Stimuli. Stimuli represented the same weather phenomena (e.g., severe thunderstorm, tornado) used during Experiment 2. For each CM subject, the target set consisted of the same three walking-dot patterns representing weather phenomena used to train that subject during Experiment 2. The CM distractor set included three walking-dot patterns and was also the same as that used during the original training for each subject. Target and distractor sets also remained the same between the present experiment and Experiment 2 for each of the VM subjects.

Procedure. Subjects performed the same type of weather pattern visual search task performed in Experiment 2. The same target/distractor mapping (CM vs VM) used with each subject in Experiment 2 was used for that subject throughout this experiment. Therefore, there were six CM and six VM subjects.

Subjects participated in two transfer sessions across 2 days of participation. Each session included five blocks of 32 training trials, for a total of 160 trials per session and 320 total transfer trials. Subjects were given the opportunity for a short break after each block of 32 trials.

As in Experiment 2, each trial began with the presentation of a target pattern to the subject. Subjects were permitted to view the target display as long as they desired, and terminated the display by pressing the button on the mouse interface. This

target display showed the physical characteristics of the target pattern, including the separation of target elements and the pattern of movement.

The target display was replaced by a search display that consisted of an outline of a map of the state of Ohio, and the target and two distractor walking-dot patterns. In addition to the target and distractor patterns, the search display also included visual background noise. This background noise was represented by random dots equal in size and shape to the dots which made up the target and distractor patterns. The amount of noise on the display at any point in time was equal to seven of these random dots. There were eight sets of these random dots presented sequentially as search time progressed. Each set was presented for 1/8 second during a 1-second scan. The display cycle continued for 7 seconds, at which time the first set of dots dropped off and a new set was added to the end of the cycle. With the exception of this background noise, all elements of the procedure remained the same as in Experiment 2.

The time required by the subject to identify the target pattern through use of the mouse interface was recorded, as were false alarms and misses. The same types of feedback used in Experiment 2 were provided to the subjects. On trials in which a hit occurred, the trial ended with a message which indicated that the target had been successfully identified. If the subject failed to find the target within the 40-second time period, the trial ended automatically and the target was highlighted.

Additional feedback was provided for the subject at the end of every block of eight trials. This feedback consisted of mean response time for hits, the number of misses, the total number of false alarms, and the percent accuracy for that block of trials. The percent accuracy measure was based on the number of trials in which no error (i.e., a false alarm or a miss) had occurred.

In addition to block summary feedback, mean response time and percent accuracy feedback for the preceding session were presented to subjects at the beginning of the second transfer session.

Design. Two independent variables were included in the design: (a) transfer sessions, and (b) mapping condition (CM vs VM).

Results

Response Time. Mean response times to detect the target pattern in both the CM and VM conditions are shown in Figure 24. This figure illustrates mean response times as a function of the last training session and both sessions of transfer. The means presented in Figure 24 are based on errorless trials in which no false alarms occurred. As can be seen in the figure, both CM and VM conditions suffered performance decrements at transfer. This was expected because transfer for both groups involved performance of the weather pattern search task under conditions of background noise as opposed to the no-background-noise condition used during training. As is also clear from the figure, decrements at transfer in both the CM and VM groups were essentially equivalent.

A 2-x-3 ANOVA was performed on the response time data to analyze the effects of mapping condition (CM vs VM) and training/transfer sessions (1-3). Mapping condition was a between-subjects variable, whereas training session was a within-subjects variable. This analysis indicated that the main effect of sessions [$F(2,20) = 203.81$, $p < .001$] was significant, but that the main effect of mapping condition [$F(1,10) = 0.21$, $p > .05$] was not. The analysis also showed that the interaction of CM/VM and sessions [$F(2,20) = 0.16$, $p > .05$] was not significant. This interaction is important to the objective of the study, which was to determine if any CM-VM differences that existed at

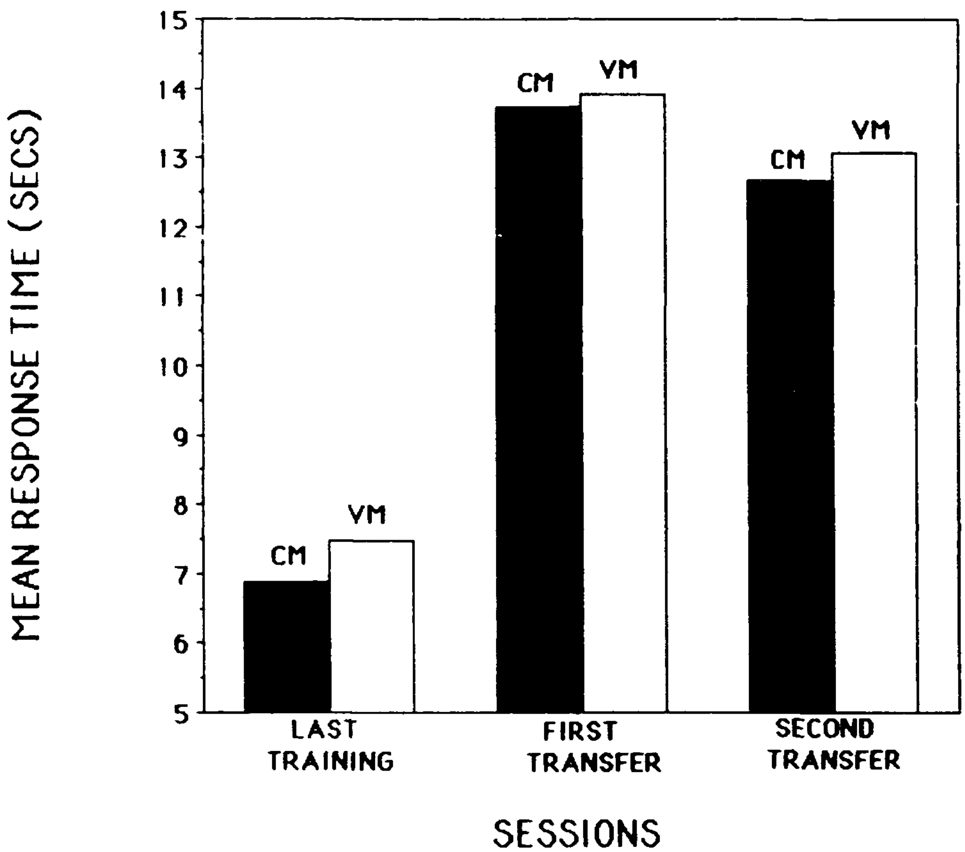

Figure 24. Mean Response Time as a Function of Mapping Condition and Training/Transfer Session.

the conclusion of training would be maintained at transfer to a more difficult search condition. The failure of the interaction indicates that there was no differential effect of training/transfer sessions on CM vs VM performance.

A Tukey-A post-hoc multiple comparison test was performed on the sessions data to further investigate the main effect of sessions that had been demonstrated. As expected, the results of this test demonstrated that transfer sessions did not differ from one another but that both were significantly different from the last training session.

Figure 25 illustrates mean standard deviation of response time as a function of mapping condition and training/transfer sessions. As shown in the figure, transfer to the noise condition had the expected effect of increasing the variability in performance; and once again, the decrements in the CM and VM conditions were approximately the same. A 2-x-3 ANOVA comparable to the mean response time analysis was performed on the data shown in Figure 25. This analysis showed that the main effect of CM/VM mapping condition was marginally significant [$F(1,10) = 3.51$, $p < .10$] and that the effect of sessions [$F(2,20) = 128.5$, $p < .001$] was significant. However, the CM-VM x sessions interaction [$F(2,20) = 0.27$, $p > .05$] did not prove to be significant. A Tukey-A post-hoc comparison test performed to investigate the significant sessions effect demonstrated that as expected, both transfer sessions differed from the last training session but were not significantly different from each other. Once again, therefore, there was no evidence of a differential effect of sessions on CM vs VM performance.

Although it was not an objective of this study to address the problem, a second issue of interest to C2 training applications concerns the benefit of training under the no-noise-level condition relative to a no-prior-training condition. The latter condition was not included in the present design, but some

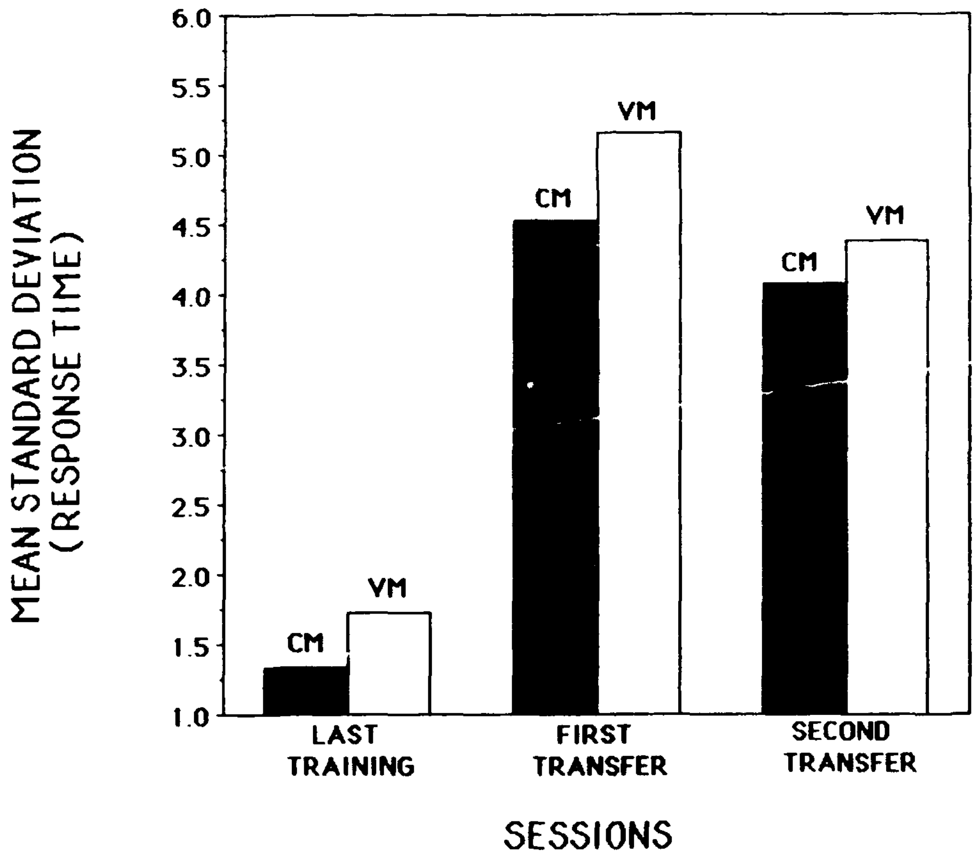

Figure 25. Mean Standard Deviation of Response Time as a Function of Mapping Condition and Training/Transfer Session.

information concerning this issue can be obtained through a comparison of the present results with those of Lawless and Eggemeier (1990). The current study used the same noise level at transfer that was used in the initial training blocks of the Lawless and Eggemeier study. Figure 26 shows mean response time from the first session of transfer in the current experiment and comparable data from the first five blocks of 32 training trials from the Eggemeier and Lawless (1990) paper. Each session in the present experiment included five blocks of 32 trials, and the Lawless and Eggemeier (1990) data illustrated were derived by building a first training session from the first five blocks of 32 trials from that experiment.

As can be seen in the figure, mean response times for the first transfer session in the present experiment are faster under both CM and VM conditions than those of the first training session in the Lawless and Eggemeier experiment. Therefore, there is some trend for positive transfer in the current experiment relative to a no-training control. It should be noted that Lawless and Eggemeier did include a familiarization training session under very-low-noise-level conditions that preceded the first formal training session, and so the Lawless and Eggemeier data can be most appropriately characterized as representing a minimal-training control. No data analyses were conducted on the data illustrated in Figure 26, and it is clear that any firm conclusions concerning positive or negative transfer relative to a no-training control would have to be based on an additional experiment that included a no-training control group. The present data do, however, suggest the possibility that positive transfer would result with such a comparison.

Accuracy of Responding. Figure 27 shows mean percent correct responses as a function of CM/VM group and training/transfer sessions. The means illustrated in Figure 27 are based on trials in which no error (i.e., false alarm, miss) occurred. As shown in the figure, response accuracy decreased in

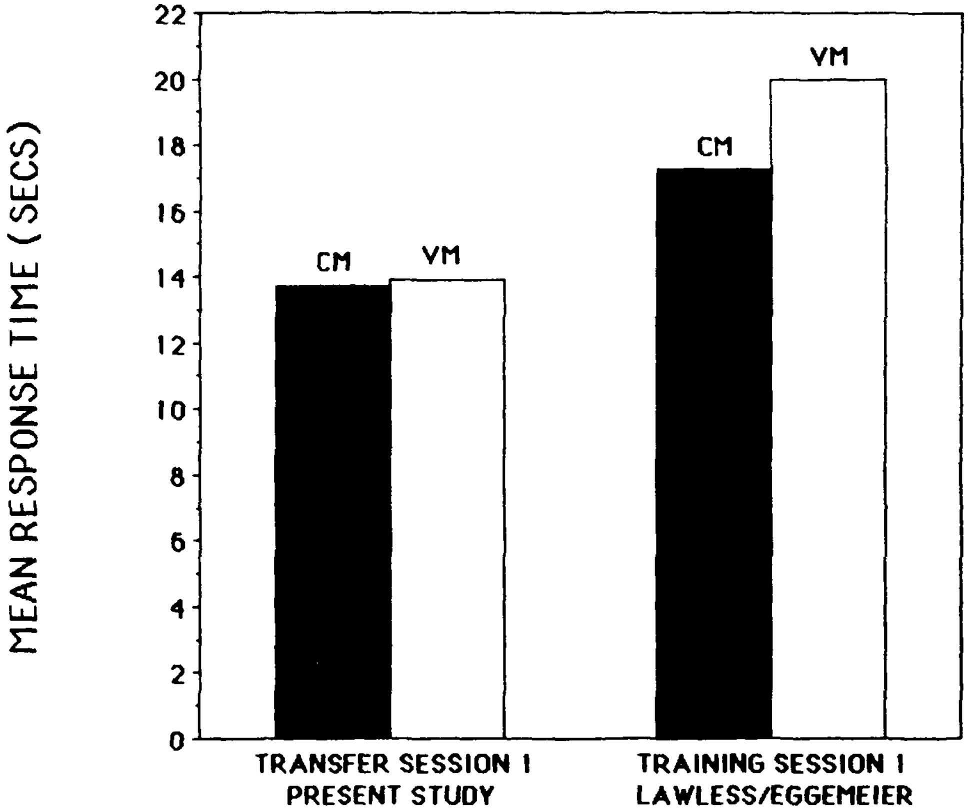

Figure 26. Mean Response Time in the First Transfer Session of the Present Study and the Lawless/Eggemeier Study.

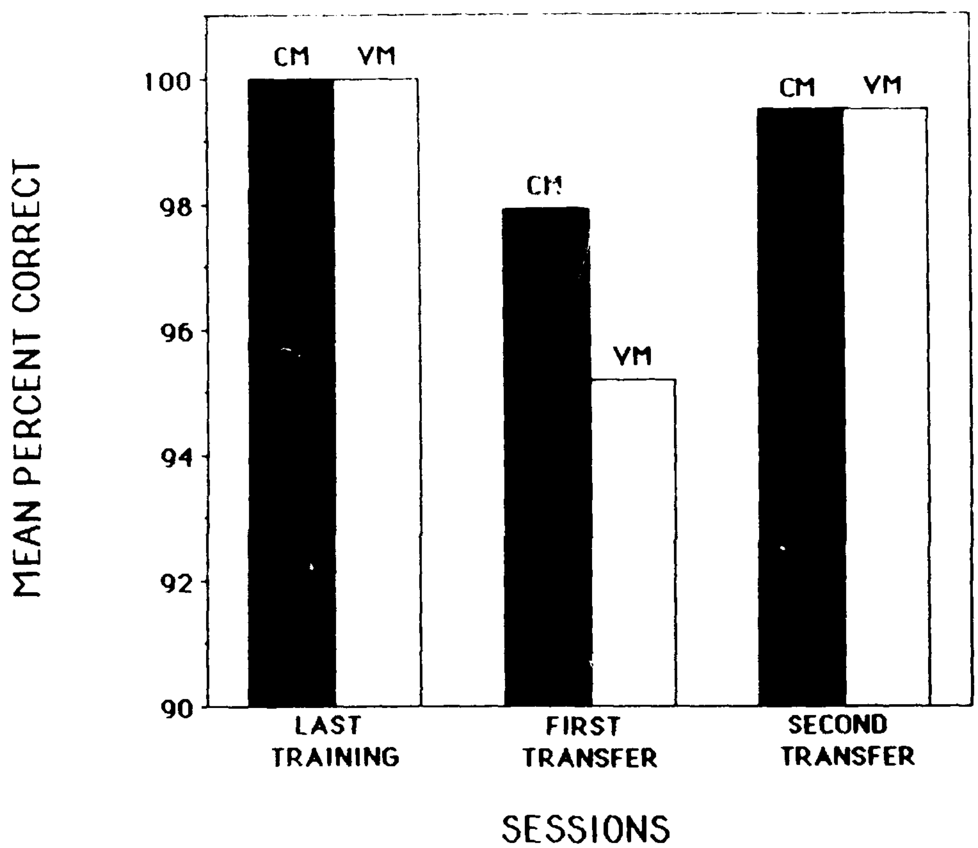

Figure 27. Mean Percent Correct as a Function of Mapping Condition and Training/Transfer Session.

both CM and VM groups at transfer to the background-noise-level conditions, but the decrements in performance for the VM group appear somewhat greater than those of the CM group.

A 2-x-3 ANOVA comparable to the response time analysis was performed on the data shown in Figure 27. This analysis demonstrated no main effect of mapping condition [$F(1,10) = 1.98$, $p > .05$] and a significant main effect of session [$F(2,20) = 15.56$, $p < .001$]. The mapping condition-x-training-session interaction [$F(2,20) = 2.77$, $p > .09$] was marginal. A Tukey-A post-hoc test performed on the sessions data showed that once again, both transfer sessions were different from training, but did not differ from one another. The main effect of sessions is therefore indicative of the performance decrements that occurred at transfer.

In addition to percent correct responses, the mean number of false alarms per trial was computed as an index of response accuracy, and is illustrated as a function of mapping condition and training/transfer session in Figure 28. As is clear from the figure, mean false alarms per trial increased in both conditions at transfer, but once more, there was a trend for VM performance to show a greater decrement during the initial transfer session than was shown by CM performance.

A 2-x-3 ANOVA was performed to examine the effects of mapping condition and training sessions on the false alarm data. This analysis indicated that once again, the main effect of sessions [$F(2,20) = 5.62$, $p < .05$] was significant and that the main effect of mapping condition [$F(1,10) = .51$, $p > .05$] was not. The mapping condition x session interaction [$F(2,20) = 1.82$, $p > .05$] also failed to demonstrate significance. A Tukey-A post-hoc test conducted on the sessions data failed to demonstrate significant differences at the .05 level between sessions.

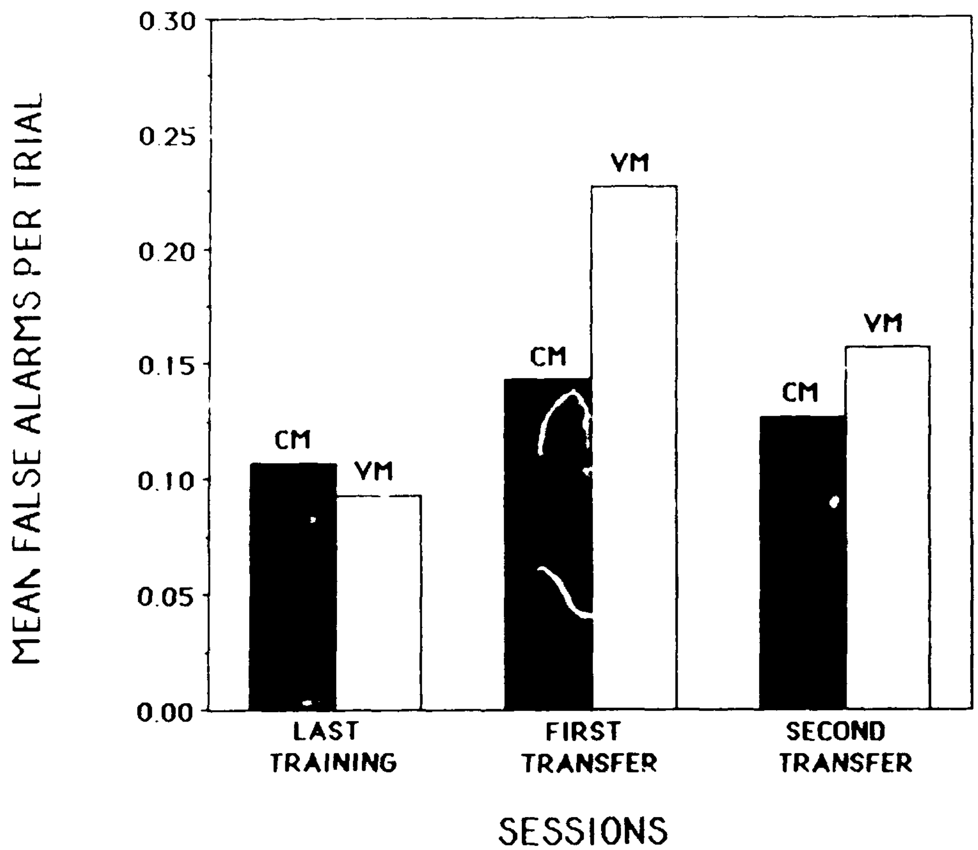

Figure 28. Mean Number of False Alarms Per Trial as a Function of Mapping Condition and Training/Transfer Session.

Discussion

The results of this study show no differential effect on CM vs VM performance of transfer from a low workload to a higher workload condition. Performance differences at the conclusion of training were minimal, however, and this seriously compromised the capability to examine differential CM-VM effects at transfer. Previous work with automatic processing [see Fisk, Ackerman, & Schneider (1987) for a review] has demonstrated resistance of CM performance to decrements under certain stressor, vigilance, and high workload dual-task conditions, and it was therefore possible that CM performance would have shown greater resistance to decrement than VM performance at transfer. The fact that this effect did not materialize can be attributed to the failure to establish reliable differences between CM and VM performance during training.

The issue of transfer from lower to higher workload variants of a task remains an important one, and should be the subject of additional research. In addition to examination of possible differential effects of such transfer on CM and VM performance, that research should also address the issue of comparison of low workload training with a no-training control group to determine the possible benefits of low workload training relative to the performance of such a group. A third group that receives equivalent levels of training on the higher workload variant of the task should also be included to complete the basis for comparison. If the task used approaches the complexity of the weather pattern search task, it would also be appropriate to include an extended transfer period to permit evaluation of both initial transfer performance and any savings in the trials or time required to reach pre-specified levels of performance in each group.

Experiment 7
Retention of Automatic Processing in a Spatial Pattern Search Task

Purpose

The purpose of this experiment was to investigate the retention of automatic processing in a memory search task that required the processing of spatial pattern information of the type investigated in Experiment 1. As noted above, there has been very little previous work to investigate the retention of automatic processes, and this type of information is essential for the development of training programs intended to permit maintenance of skills over periods of disuse. Because of the critical role played by spatial pattern information in many Air Force C2 systems, it was considered important to extend the previous work of Fisk et al. (1990) with semantic category search to a task that involved the processing of spatial patterns. Therefore, the present experiment was performed to investigate the retention of static spatial pattern information in a memory search task that was the same as the one used during Experiment 1 to demonstrate the development of automatic processing with this type of information.

Because the Fisk et al. (1990) work had suggested that the majority of forgetting with semantic information occurred during the first 30 days of a 6-month period, a 30-day retention interval was employed in this experiment. In addition, retention was tested at 48 hours after completion of the last training session. At each of these retention intervals, subjects completed two full sessions of retraining on the spatial pattern search task. This procedure permitted the assessment of retention through examination of the levels of performance over the first block of retraining trials in each session. By examining performance at the conclusion of the last retraining session, the procedure also provided the opportunity to assess the capability

of subjects to regain any losses in performance that might have occurred during the retention interval. This latter issue was considered of substantial practical importance, in that the objective of any refresher or skill maintenance training would be to return operators to criterion proficiency levels achieved at the conclusion of original training.

Method

Subjects. Subjects were 10 University of Dayton students. They were paid $4.00 per hour for their participation. In addition to this base rate of pay, subjects were awarded a bonus payment of $1.00 per hour for appearing on time for each scheduled experimental session. Twelve subjects originally participated. One CM subject was eliminated for failure to achieve acceptable levels of performance. The VM counterpart of that subject was also eliminated to maintain proper counterbalancing of stimulus materials used in the two mapping conditions.

Apparatus. The experiment was controlled with a Zenith Data Systems 248 computer, programmed to present stimuli, control the timing of stimulus presentation, and collect subject responses. Subjects viewed spatial pattern stimuli on a Zenith ZCM-1490 high-resolution color monitor. Responses were made on the arrow keys located in the lower right-hand corner of a standard expanded IBM-compatible keyboard. Auditory feedback concerning performance levels was presented to subjects through the speakers on the Zenith computers.

Procedure. Subjects performed a memory search task which was modeled after the Sternberg (1966) paradigm. On each trial, subjects were shown a memory set of one to four spatial patterns on the computer cathode-ray tube (CRT) screen. These spatial patterns remained on the screen until the subject pressed a designated key on a computer keyboard. At this point, a fixation

cross 4.5 mm in height and 4.3 mm in width appeared in the middle of the screen for 500 ms. The fixation cross was replaced by a single test pattern displayed for a maximum of 2 seconds or until the subject responded.

The subject was instructed to rapidly determine whether the test pattern was a member of the previously presented memory set. Subjects responded "yes" or "no" by pressing with their preferred hand a labeled response button on the keyboard. One-half of the target patterns in each block of trials were members of the memory set; the other patterns were not members of the set. Two dependent measures, reaction time and response accuracy, were collected. Each subject was encouraged to respond as rapidly as possible while maintaining an accuracy level of 90% or higher within each session.

Both visual feedback and auditory feedback were provided to subjects at the completion of each trial. After each trial, an incorrect response was followed by a "Wrong Response" message on a red background, and by a tone. A correct response was followed by a "Correct Response" message on a blue background, the reaction time for that trial, and a short musical sequence for those reaction times below a specified criterion. In addition, the feedback concerning correct responses also included a message specifying the level of performance indicated by the reaction time achieved. This feedback indicated to the subject if the level was that of a "Novice," "Professional," "Expert," or "Ace." These levels represented progressive decreases in reaction time to the spatial pattern information, and the feedback encouraged the subject to attempt to lower reaction time if only the "Novice" level had been achieved on a particular trial. Performance categories were based on reaction times achieved by subjects in a pilot study that preceded the present experiment.

Additional summary feedback was provided at the beginning of each day of training following the initial training day. This

feedback summarized reaction time and accuracy performance levels from each of the previous training days, and provided a means for subjects to follow changes in their performance as a function of training.

The experiment was divided into two phases: (a) training, and (b) retention. Subjects participated in the training phase of the experiment for 10 days. On each acquisition day, subjects completed two 30-minute training sessions which consisted of 10 blocks of 20 trials each. Therefore, there were 400 training trials each day and a total of 4,000 training trials during the first phase of the experiment.

During the retention phase of the experiment, subjects returned for two retraining periods that consisted of two sessions each. Each session included 10 blocks of 20 retraining trials, for a total of 400 blocks of retraining. The first retraining period took place 2 days after the completion of the last training session, while the second retraining period was conducted 30 days after the completion of the last training session.

Each retraining period included a series of 200 warm-up trials prior to the start of the actual retraining sessions. These warmup trials involved performance of a memory search task with digits, and were intended to re-familiarize subjects with the general procedures of the experiment with a type of material that was not expected to provide any specific transfer to the spatial pattern information under investigation.

The spatial patterns used during the retraining sessions were the same as those used during the original training sessions for each subject. Mapping conditions also remained consistent throughout training and retention testing for each subject.

Stimulus Materials. Each spatial stimulus pattern was composed of five circular elements and was intended to represent the type of pattern processed by operators of certain Air Force systems. The same target/distractor sets used in Experiment 1 were also used in the present experiment. Each set of patterns included four targets and four distractor patterns.

Design. Three independent variables were included in the design: (a) target/distractor mapping, (b) memory set size, and (c) training/retraining sessions. Target/distractor mapping was either CM or VM, and represented a between-subjects variable. Five subjects were assigned to the CM group and five subjects to the VM group. In the CM condition, one set of spatial patterns served as targets throughout training for an individual subject, and a second set served as distractor patterns. In the VM condition, sets of target patterns served as both targets and distractors across blocks of trials. Five different sets of spatial pattern stimuli were distributed across subjects in both the CM and VM conditions. Under CM conditions, four items of a set served as targets and the remaining four items served as distractors. In VM conditions, targets and distractors were drawn at random on a trial-by-trial basis from the total set of eight items included in a pattern set. Each pattern set served as targets/distractors for one CM subject and for one VM subject. Memory set size was manipulated within blocks of trials in each group, and consisted of one to four spatial patterns. Each group completed 20 sessions of practice trials across the 10 days of training and two sessions of practice trials during each of the two retraining periods.

Results

Training Analysis. Mean reaction time to test patterns as a function of CM/VM condition and training sessions is illustrated in Figure 29. The means depicted in Figure 29 are based on correct responses by subjects. As was the case in Experiment 1,

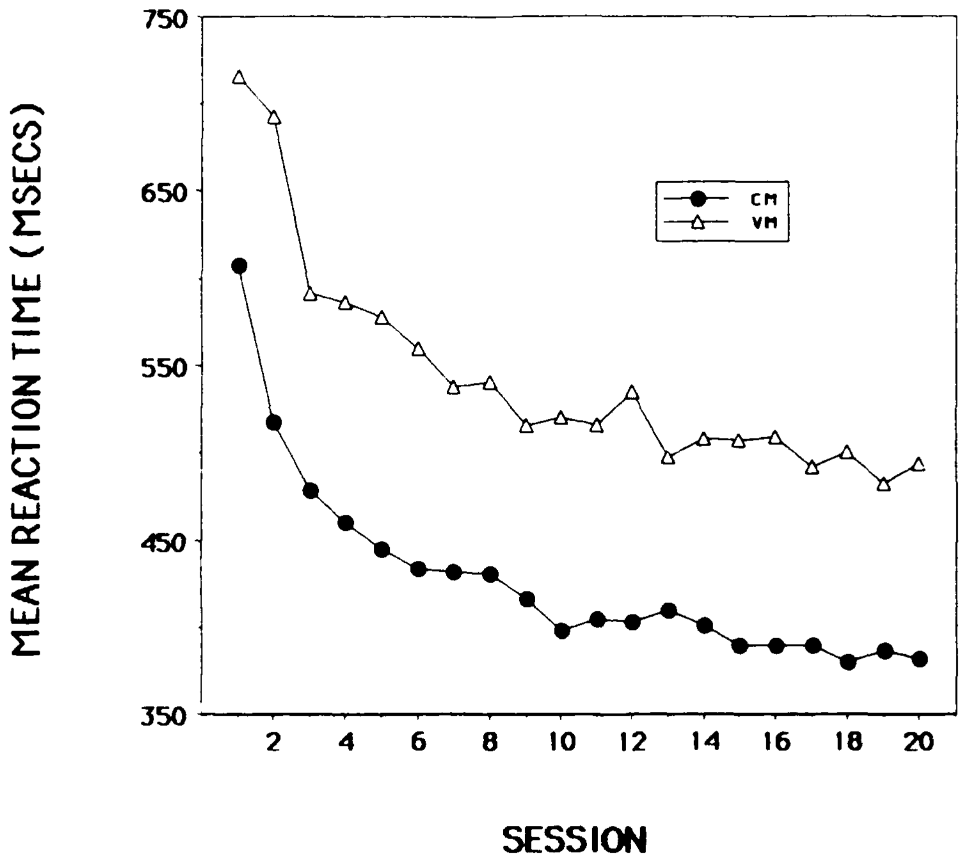

Figure 29. Mean Reaction Time as a Function of Mapping Condition and Training Session.

both CM/VM condition and training sessions had a substantial effect on reaction time. Once again, the CM group exhibited a consistent advantage in reaction times relative to the VM group. The performance of both groups improved as a function of training.

A 2-x-4-x-20 ANOVA was performed on the reaction time data to analyze the effects of mapping condition (CM vs. VM), memory set size (1-4), and training session (1-20). Mapping condition was a between-subjects variable in this analysis, whereas memory set size and training session were within-subjects variables. The results of this analysis demonstrated that the main effects of mapping condition [$F(1,8) = 6.66$, $p < .04$], memory set size [$F(3,24) = 71.54$, $p < .001$], and training sessions [$F(19,152) = 17.94$, $p < .001$] were significant. The interactions of CM/VM x memory set [$F(3,24) = 15.55$, $p < .001$] and memory set x session [$F(57,456) = 2.84$, $p < .001$] were also significant. However, neither the CM/VM x sessions interaction nor the three-way interaction proved significant.

The reaction time results from the training phase of this experiment are consistent with the results of Experiment 1, and with the development of some degree of automatic processing in the CM condition. The CM group demonstrated reliably faster reaction times across training sessions than those of the VM group, and this effect is one indicant that supports the development of automatic processing under CM conditions. The significant main effects of sessions and memory set size were expected in this paradigm on the basis of the Experiment 1 results, and indicate that the performance of both mapping groups improved with training and that memory set size exerted its anticipated effect on reaction time. The main effects are therefore consistent with previous results and with the development of automatic processing in the CM group.

In addition to reaction time differences between CM and VM groups, a second criterion to evaluate the development of automatic processing is a greater reduction in the effect of task demand within the CM group versus the VM group as training progresses. Within the memory search paradigm, this reduction takes the form of a greater attenuation of memory set size effects in the CM vs the VM group at the conclusion of training. The significant CM/VM x memory set interaction reported above is consistent with the presence of a differential effect of memory set size within the CM and VM groups.

Figure 30 shows the effect of memory set size on reaction time in the CM and VM groups for both the first and last sessions of training. As can be noted from the figure, memory set size had a substantial effect on both CM and VM performance during the first training session. Subsequent to the reliable CM/VM x memory set interaction, tests of simple effects of memory set size within the CM group and within the VM group were performed on the Session 1 data. These tests were conducted to assess the effect of memory set size on reaction time performance within each group at the beginning of training. These analyses showed that the effect of memory set was significant within both the CM [$F(3,24) = 9.16$, $p < .001$] and VM [$F(3,24) = 16.49$, $p < .001$] conditions. Tukey-A post-hoc multiple comparison tests showed that within the VM condition, reaction times associated with memory set size one differed reliably ($p < .05$) from those associated with all other conditions, and that reaction times of memory set size four were significantly longer than those associated with memory set size two. Within the CM condition, reaction times of memory set size one differed from those of all other sizes, but no other differences were significant. Tests of simple effects of memory set during Session 20 failed to demonstrate a set-size effect in the CM condition [$F(3,24) = 2.95$, $p > .05$], but did show an effect of set size within the VM condition [$F(3,24) = 36.07$, $p < .001$]. This analysis therefore indicated that by Session 20, memory set no longer reliably affected CM reaction time performance. Tukey-A

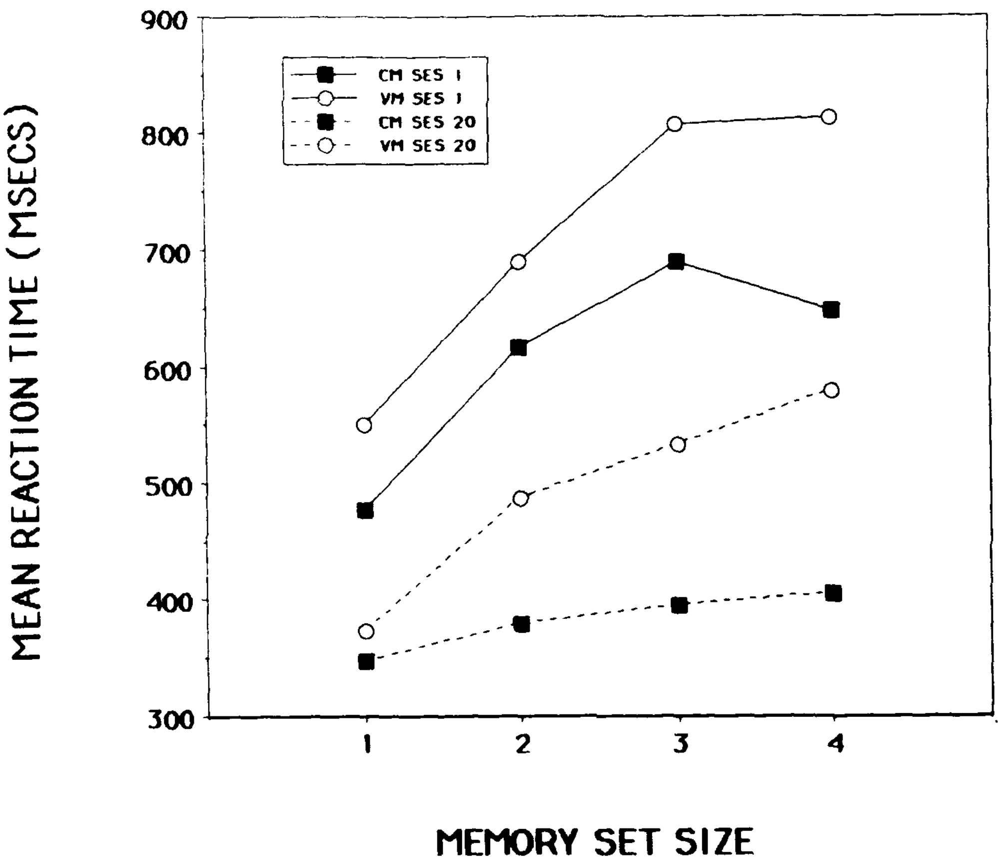

Figure 30. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Training Session.

comparisons performed with the Session 20 VM data demonstrated exactly the same pattern as was shown by comparable analyses of the Session 1 VM data, indicating that there had been no reliable change in the pattern of memory set size effects as a result of training in the VM condition. These results are therefore consistent with the development of some level of automatic processing within the CM condition but not within the VM condition.

To further characterize the reductions in memory set size on reaction time performance, slopes of the functions depicted in Figure 30 were computed. Within the CM group, the slope of the Session 1 function was 58.8 ms and was reduced to 18.8 ms during Session 20. In contrast, the slope of the Session 1 function in the VM group was 90.8 ms, but was reduced only to 66.3 ms by Session 20. The CM group demonstrated a 68% reduction in slope with training as compared to a 27% reduction in the VM group. This type of CM-VM difference is also consistent with the development of automatic processing under CM conditions.

Figure 31 shows mean percent correct responses as a function of CM/VM group and training session. As is clear from the figure, response accuracy was consistently high and generally improved in both groups as a function of training.

A 2-x-4-x-20 ANOVA comparable to that performed on the reaction time data was conducted on the percent correct responses. This analysis demonstrated no main effect of mapping condition [$F(1,8) = 1.34$, $p > .25$], a reliable effect of memory set size [$F(3,24) = 30.19$, $p < .001$], and a significant main effect of training sessions [$F(19,152) = 2.97$, $p < .001$]. The CM/VM x memory set interaction [$F(3,24) = 8.72$, $p < .001$] was significant, but all other interactions were not. The main effect of training session reflects the trend for increased accuracy in both mapping groups over the initial training sessions that was

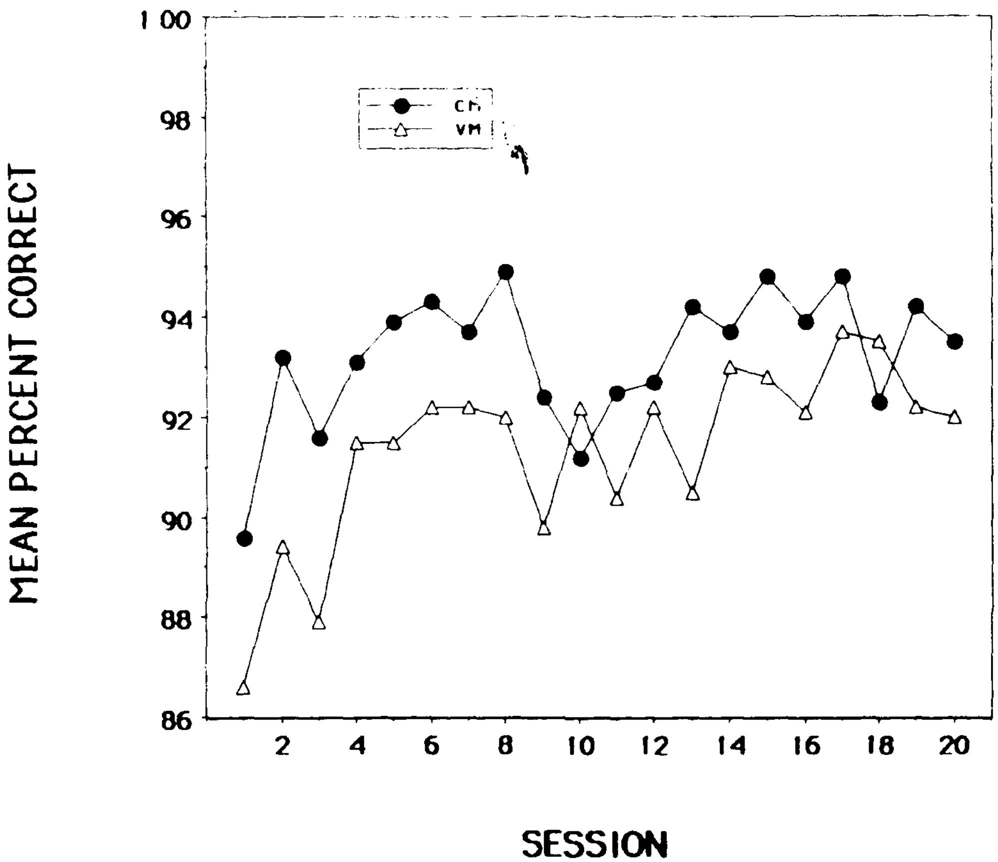

Figure 31. Mean Percent Correct as a Function of Mapping Condition and Training Session.

noted in the discussion of Figure 31. The failure to find a main effect of mapping condition and the general trend for increased accuracy in both groups indicates that the difference in reaction times noted in Figure 29 cannot be attributed to a significant speed-accuracy tradeoff.

Figure 32 illustrates the effect of memory set size on CM and VM mean percent correct during Session 1 and during Session 20. As shown in the figure, CM performance was generally more accurate than VM performance, and there was also a general trend for percent correct to decrease as memory set size increased. Tests of simple effects on the Session 1 data conducted subsequent to the reliable CM/VM x memory set interaction showed that memory set significantly affected performance in the VM condition [$F(3,24) = 4.63$, $p < .05$] but not in the CM condition [$F(3,24) = 0.70$, $p > .05$]. A Tukey-A post-hoc comparison test showed that memory set size one was associated with a reliably ($p < .05$) higher percent correct than was memory set size four in the VM condition. No other differences proved to be reliable. Tests of simple effects within the Session 20 data produced similar trends, and showed a reliable effect of memory set size on VM performance [$F(3,24) = 5.19$, $p < .05$] but not on CM performance [$F(3,24) = 1.41$, $p > .05$]. A Tukey-A post-hoc test demonstrated that memory set size one produced significantly higher levels of performance than did memory set sizes of three and four patterns. These results and the fact that Session 20 CM performance exceeded Session 1 CM performance and Session 20 VM performance at the three highest memory set sizes indicate that the previously described attenuation of memory set size effects in the CM reaction time data are not attributable to a speed-accuracy tradeoff.

The results of the training phase of this experiment are, therefore, consistent with the development of automatic processing with the static spatial pattern materials that were used. The results of this phase of the experiment are similar to

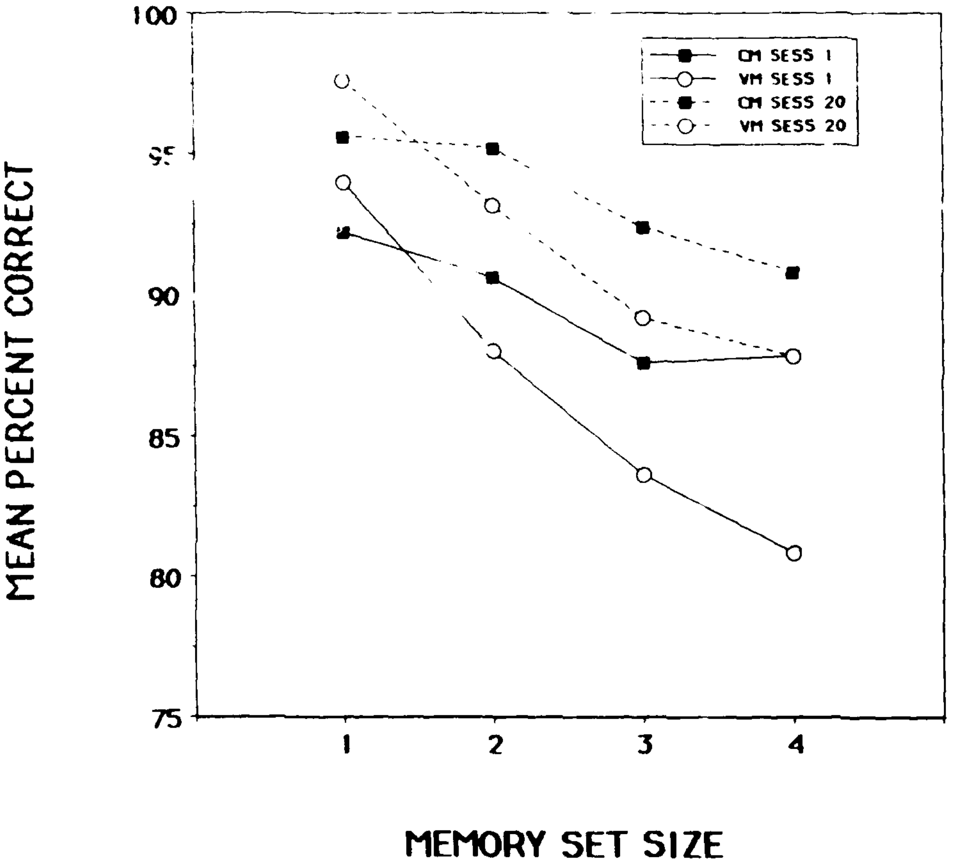

Figure 32. Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Training Session.

those of Experiment 1, and provide additional data to extend the results of earlier work with static spatial pattern information (Eggemeier et al., 1990) that demonstrated the development of automatic processing with this type of material.

Retention Analysis. Figure 33 shows mean reaction time as a function of mapping condition in the last trial block of the training phase, the first test block of the 2-day retention interval, and the first test block of the 30-day retention interval. Mean reaction times in the figure are based on correct responses in blocks of 40 trials. Blocks of 40 trials were used in this analysis to provide a more sensitive assessment of retention effects than would have been provided by an analysis based on sessions of 200 trials. As is clear from the figure, differences between CM and VM performance present at the conclusion of training were maintained over both the 2-day and 30-day retention intervals. There is also little evidence of any substantial loss of information across the retention intervals, although there does appear to be a slight trend for increases in reaction times at each successive retention interval, particularly in the VM group.

A 2-x-4-x-3 ANOVA was performed on the data illustrated in Figure 33 to evaluate the effects of mapping condition (CM vs VM), memory set size (1-4), and training/retention blocks (last training block vs first 2-day retention block vs first 30-day retention block) on performance. This analysis demonstrated a marginally significant effect of mapping condition [$F(1,8) = 5.03$, $p < .06$]; a main effect of memory set size [$F(3,24) = 29.22$, $p < .001$]; and most important, no main effect of trial blocks [$F(2,16) = 1.64$, $p > .20$]. The CM/VM x memory set interaction was reliable [$F(3,24) = 11.33$, $p < .001$], but none of the other interactions were significant. This analysis therefore confirms the trends noted above, and indicates that over the retention intervals tested, the performance losses illustrated in Figure 33 were minimal.

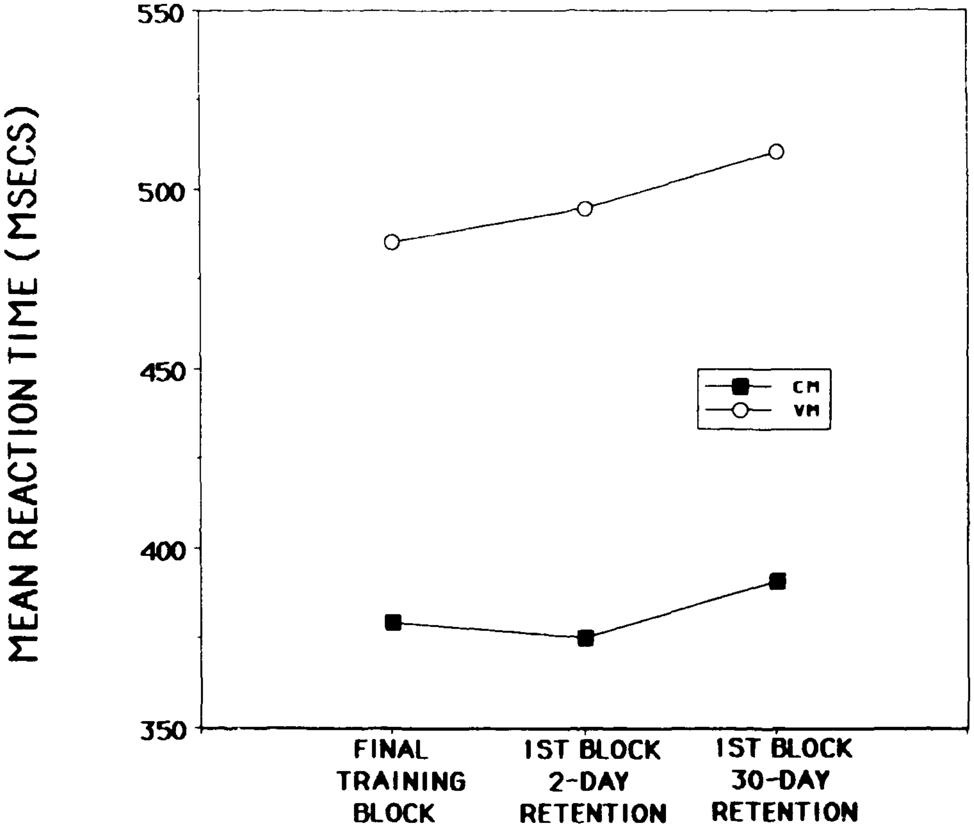

Figure 33. Mean Reaction Time as a Function of Mapping Condition and Training/Retention Block.

Figure 34 shows mean reaction time as a function of memory set size and mapping condition during the last block of training and the first block of the 2-day retention test. As is clear from the figure, CM performance in both instances shows little difference, whereas VM performance at the higher memory loads demonstrates a slight tendency to deteriorate. Tests of simple main effects of memory set size within the CM group and within the VM group performed on the last block of training subsequent to the significant CM/VM x memory set interaction indicated that as expected, memory set size had no reliable effect on CM reaction times [$F(3,24) = 0.67$, $p > .05$]. Memory set size did, however, significantly influence VM reaction times [$F(3,24) = 20.67$, $p < .001$]. A Tukey-A post-hoc comparison test performed on the VM data showed that reaction times associated with memory set size one differed reliably ($p < .05$) from the reaction times produced by all other memory sets. There were no other significant differences.

Tests of simple effects of memory set size within the CM and VM conditions on the first block of the 2-day retention test indicated that memory set reliably affected both CM [$F(3,24) = 3.17$, $p < .05$] and VM [$F(3,24) = 40.98$, $p < .001$] reaction times. A Tukey-A post-hoc comparison test failed to identify any reliable ($p < .05$) differences in reaction times between memory set sizes within the CM condition. This failure to find reliable differences with the post-hoc comparison test following the significant F-test can be attributed to the fact that the Tukey-A is a relatively conservative multiple comparison test which would not be expected to be as sensitive as the F-test, and also reflects the very modest differences in CM reaction time between the last block of training and the first block of the retention test that are illustrated in Figure 34. In fact, the most substantial difference between CM performance levels associated with the last block of training and the first block of the 2-day retention test actually reflects a slight improvement in

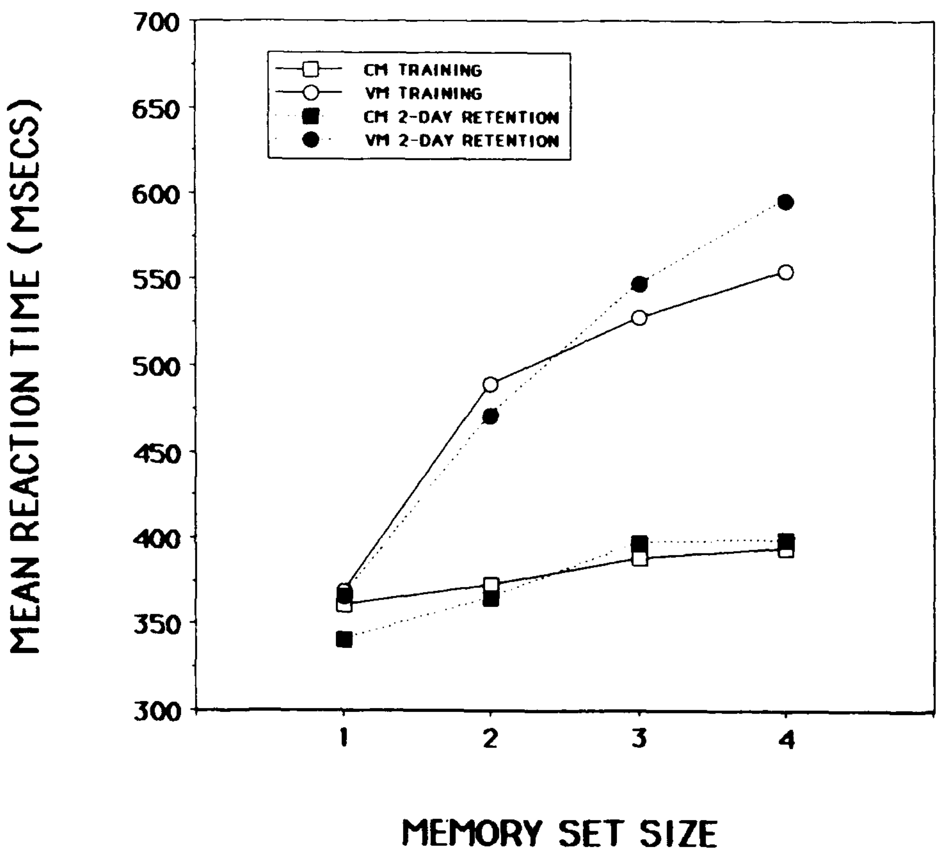

Figure 34. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Training/Retention Block.

performance under the memory-set size-one condition during the retention test.

A Tukey-A test of the VM 2-day retention data did, however, indicate that memory-set size-one reaction times differed significantly from those associated with all other memory set sizes, and also showed that memory-set size-two reaction times were reliably different from memory-set size-three and memory-set size-four reaction times. These latter differences had not proven reliable in the post-hoc comparisons performed on the VM data from the last block of training. The results of these analyses are therefore consistent with the general trends noted above, and suggest that while no appreciable deterioration had occurred within the CM group at the 2-day retention interval, some minimal losses had occurred within the VM group.

Slopes of the functions illustrated in Figure 34 showed an initial level of 11.3 ms for the CM condition at the completion of training versus a level of 20.6 ms during the 2-day retention test. Comparable VM slopes were 59.9 ms at the completion of training and 76.6 ms at the 2-day retention interval. The CM group therefore showed an 8.7-ms decrement in performance along this dimension, while the VM group demonstrated a 16.7-ms decrement in slope over the course of the 2-day retention period. As noted above, both groups therefore showed minimal losses in performance. However, the VM slope decrement was approximately twice the size of the CM decrement.

Essentially the same pattern of results emerged from analysis of the 30-day retention interval data. Figure 35 shows mean reaction time as a function of memory set size and mapping condition during the last block of training and the first block of the 30-day retention test. As can be seen in the figure, CM performance at 30 days shows little difference from the last block of training. VM performance is also very similar to the training baseline, but again demonstrates some tendency to

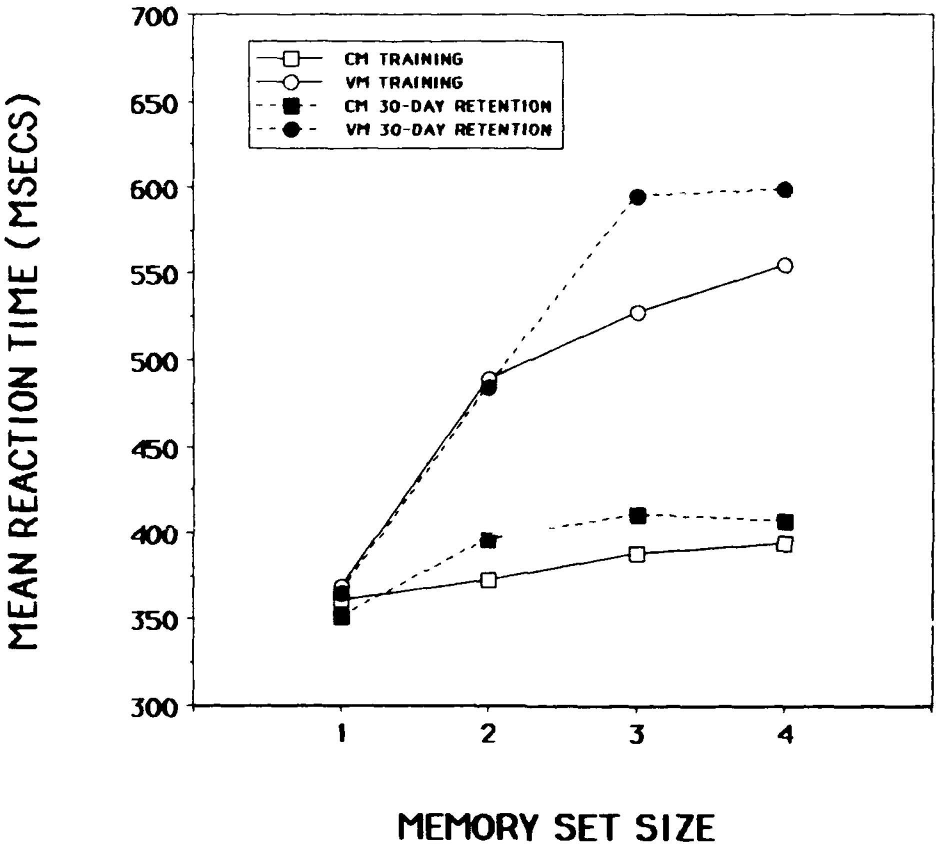

Figure 35. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Training/Retention Block.

deteriorate at higher memory set sizes. Tests of simple effects of memory set on reaction time within the CM and VM conditions on the first block of the 30-day retention test confirmed these trends, and showed that memory set size had a reliable effect on VM reaction times [$F(3,24) = 18.13$, $p < .001$], but not on CM reaction times [$F(3,24) = 1.07$, $p > .05$]. A Tukey-A comparison test performed on the VM data demonstrated the same pattern as was shown in the 2-day retention analysis, and indicated that memory-set size-one reaction times differed reliably ($p < .05$) from those of all other memory set sizes, and that memory-set size-two reaction times were shorter than those associated with memory-set sizes of three and four patterns.

Slopes of the functions illustrated show a level of 17.8 ms for the CM group during the 30-day retention test and a slope of 81.2 ms in the VM group. The CM group therefore showed a 6.5-ms slope decrement in performance at 30 days, whereas the VM group demonstrated a 21.3-ms decrement over a comparable time period. The deficit in the VM group was therefore approximately three times greater than the CM deficit, representing an increase in the relative deficits from those demonstrated at the 2-day retention interval.

Figure 36 shows mean percent correct responses as a function of mapping condition in the last trial block of training and the first test block of the 2-day retention interval and the first test block of the 30-day retention interval. Mean percent correct responses in the figure are based on blocks of 40 trials. As can be seen in the figure, accuracy of responding remained high, but showed some tendency for small decrements across retention intervals.

A 2-x-4-x-3 ANOVA comparable to the analysis performed on the reaction data was conducted on the data illustrated in Figure 36. This analysis evaluated the effects of mapping condition (CM vs VM), memory set size (1-4), and training/retention blocks

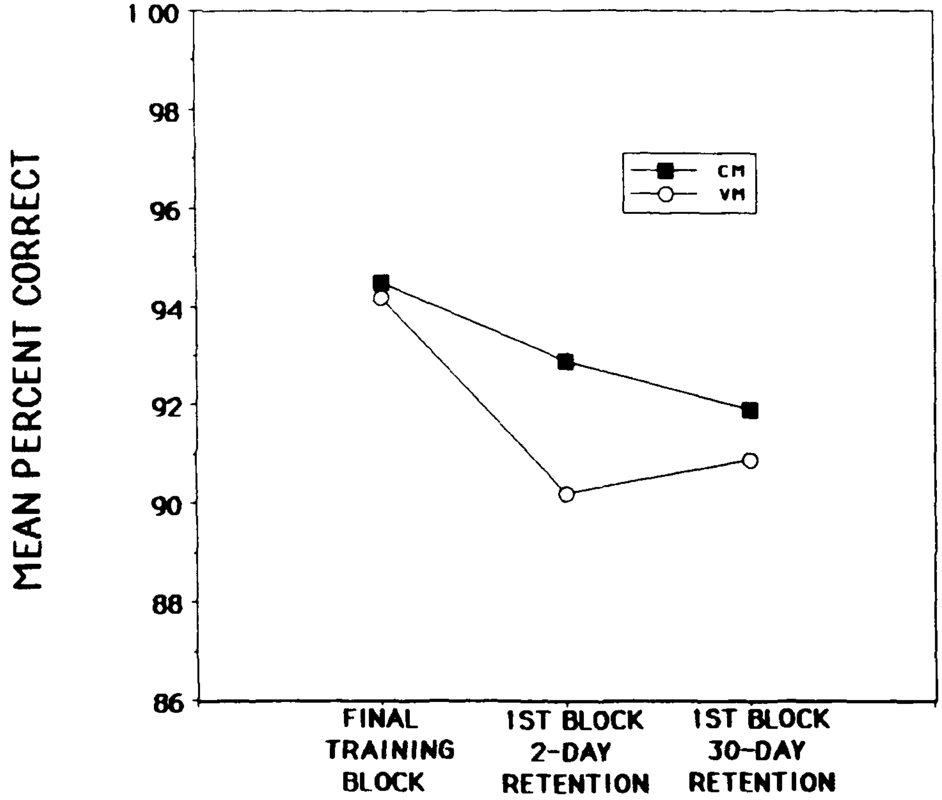

Figure 36. Mean Percent Correct as a Function of Mapping Condition and Training/Retention Block.

(last training block vs first 2-day retention block vs first 30-day retention block) on percent correct performance. Results of this analysis showed that the main effects of mapping condition [$F(1,8) = 0.34$, $p > .55$], memory set size [$F(3,24) = 1.74$, $p > .15$], and trial blocks [$F(2,16) = 1.79$, $p > .15$] were all non-significant. None of the interactions proved significant. The results of this analysis are therefore consistent with the trends noted in Figure 36, and indicate that there was no significant deterioration in the accuracy of performance over the retention intervals tested.

Retraining Analysis. In addition to evaluation of retention of spatial pattern information, comparison of the final trial block of training with the final trial blocks of retraining under both the 2-day and 30-day retention intervals permits evaluation of the effect of relatively short retraining periods on performance under CM and VM performance conditions. Figure 37 shows mean reaction time as a function of mapping condition for the last block of training, the last block of the 2-day retention interval retraining session, and the last block of the 30-day retention interval retraining session. Mean reaction times presented in the figure are based on correct responses in blocks of 40 trials. As was the case with the retention data presented above, there is a clear effect of mapping condition on performance at the completion of the training and retraining sessions, with the CM group demonstrating the advantage. There is also a trend for the VM group to show an inability to completely recover the levels of performance achieved at the completion of original training. This inability is most marked at completion of the 30-day retention interval retraining.

A 2-x-4-x-3 ANOVA was performed on the data illustrated in Figure 37 to evaluate the effects of mapping condition (CM vs VM), memory set size (1-4), and training/retraining blocks (last training block vs last 2-day retraining block vs last 30-day retraining block) on performance. This analysis demonstrated a

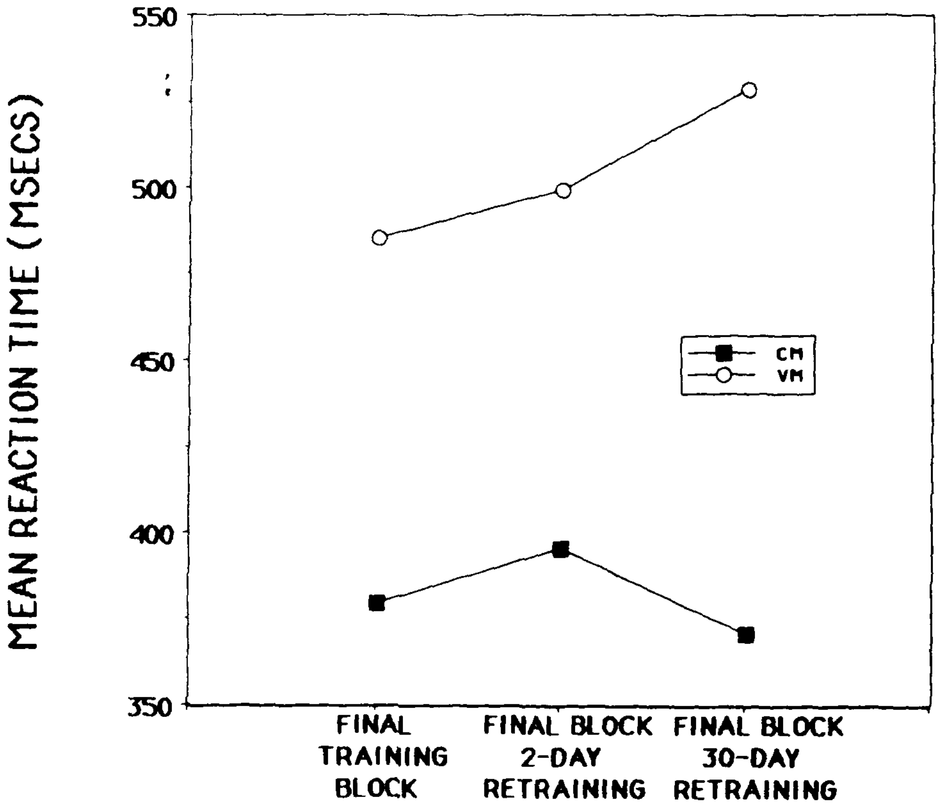

Figure 37. Mean Reaction Time as a Function of Mapping Condition and Training/Retraining Block.

significant effect of mapping condition [$F(1,8) = 6.29$, $p < .04$], a main effect of memory set size [$F(3,24) = 28.32$, $p < .001$], but no main effect of retraining blocks [$F(2,16) = 1.69$, $p > .20$]. However, the CM/VM x blocks interaction did prove reliable [$F(2,16) = 4.34$, $p < .04$], as did the CM/VM x memory set interaction [$F(3,24) = 12.08$, $p < .001$]. None of the other interactions were significant.

Tests of simple main effects were conducted to further investigate the significant CM/VM x training/retraining blocks interaction. These analyses examined the effect of training/retraining blocks under CM and VM conditions, respectively. Neither the CM analysis [$F(2,8) = 3.46$, $p < .10$] nor the VM analysis demonstrated a significant effect of blocks [$F(2,8) = 2.90$, $p < .15$]. Therefore, the tendency for the VM group to show some deterioration in performance as retraining blocks progressed was non-significant, as were the variations in performance within the CM group. The interaction therefore reflects the tendency for the discrepancy in CM versus VM performance to become more pronounced at the conclusion of the 30-day retraining session in comparison with the performance discrepancies at the conclusion of original training and the 2-day retraining interval.

Figure 38 shows mean reaction time as a function of memory set size and mapping condition in the last block of training and the final block of the 30-day retention interval retraining session. As can be seen in the figure, CM performance at the conclusion of the retraining session is very similar to that for the final training block, and actually demonstrates a slight improvement over original performance levels at some memory set sizes. VM performance, on the other hand, reflects the trend noted above and shows a tendency toward decrement at the conclusion of retraining versus original training levels. As was the case with the retention data, this tendency is most marked at the higher memory set sizes.

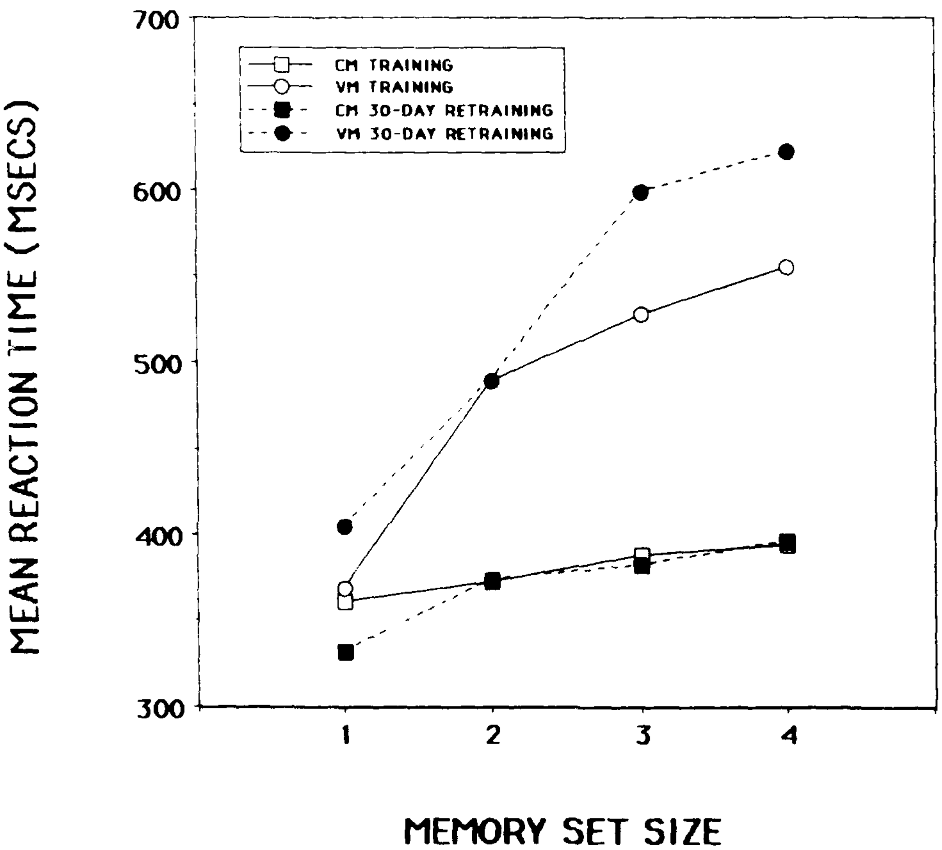

Figure 38. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Training/Retraining Block.

Figure 39 illustrates mean percent correct as a function of mapping condition for the last block of training, the last block of the 2-day retention interval retraining session, and the last block of the 30-day retention interval retraining session. As shown in the figure, response accuracy remained high across blocks, although there was a slight tendency for accuracy to decline in the final block of retraining in both the CM and VM conditions.

A 2-x-4-x-3 ANOVA was conducted on the data illustrated in Figure 39. This analysis evaluated the effects of mapping condition, memory set size, and training/retraining blocks (last training block vs last 2-day retention interval retraining block vs last 30-day retention interval retraining block) on percent correct responses. Results of this analysis showed that the main effect of mapping condition [$F(1,8) = 0.24$, $p > .60$] was non-significant, that the effect of trial blocks was marginal [$F(2,16) = 3.49$, $p < .06$], and that the effect of memory set size [$F(3,24) = 3.32$, $p < .05$] was significant. None of the interactions were reliable. The results of this analysis are therefore consistent with the trends noted in Figure 39, and indicate that the decline in performance at the conclusion of the last retraining session approached, but did not attain, significance.

Discussion

The results of this experiment indicate that over the 30-day retention interval that was tested, very minimal losses of performance occurred within CM memory search performance. A similar pattern emerged within the VM group, although the trend toward loss of performance was more marked in this group than in the CM group. The tendency for losses in performance within the VM group was most notable at higher memory set sizes, where CM performance typically demonstrates its greatest superiority over

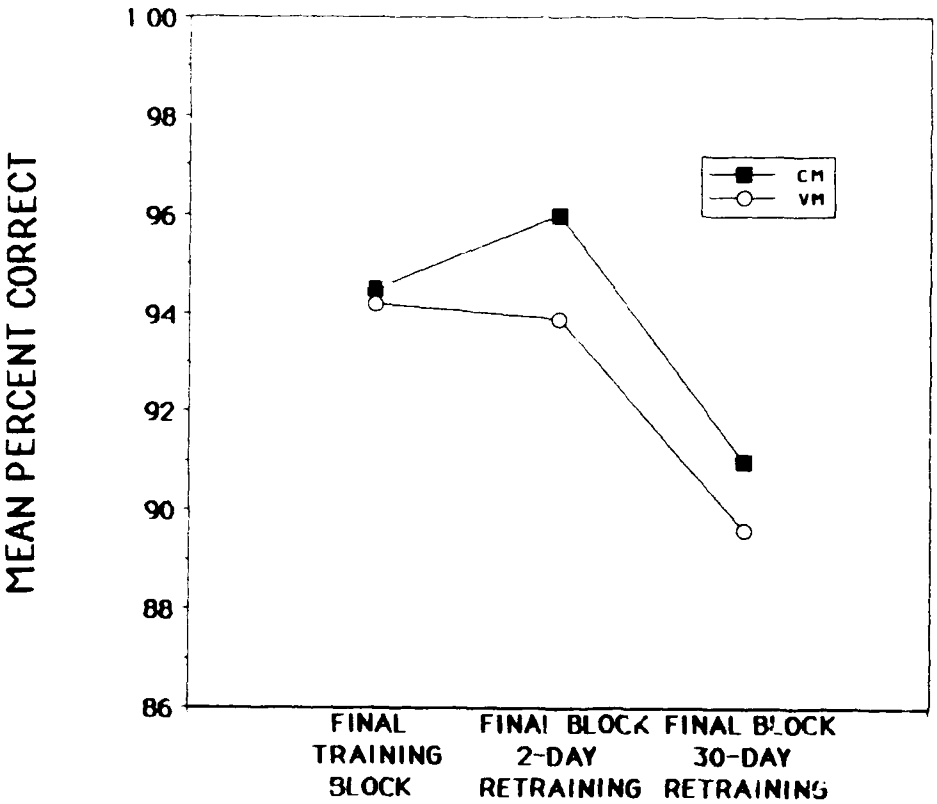

Figure 39. Mean Percent Correct as a Function of Mapping Condition and Training/Retraining Block.

VM performance in a memory search paradigm.

There are important practical implications of these results, because they suggest that no retraining would be required over 30-day periods to maintain CM memory search performance at original levels under the conditions of training used in the current experiment.

The present results therefore extend the work of Fisk et al. (1990), who reported no loss of CM performance over a 30-day interval in a pure memory search task with semantic category information. Given that Fisk et al. did demonstrate some performance loss over 30 days in a hybrid visual/memory search paradigm, future research should examine the issue of the retention of spatial pattern information within either a visual search paradigm or a hybrid visual/memory search task.

Additional areas for research that would be important to C2 operator training applications include an examination of retention functions for the more complex dynamic spatial patterns investigated in Experiment 3. Similar work should be conducted with the rule-based alphanumeric task investigated in Experiments 4 and 5. Both of these types of information are representative of information that must be processed within the context of some C2 systems, and it would therefore be important to extend the current findings to these areas as well.

General Discussion

Experiments 5 and 6 investigated the transfer that occurred within a complex alphanumeric rule-based task and a task that required search for dynamic spatial pattern information, respectively. The pattern of transfer exhibited in Experiment 5 was consistent with expectations, and suggested a tendency for positive transfer to untrained exemplars of trained rules with the alphanumeric information investigated. As noted previously,

such transfer would be extremely important to eventual applications of an automatic-processing-based approach to C2 operator training. The results of the pre-transfer phase of Experiment 5 are also significant because they provide stronger evidence of CM vs hybrid VM differences than were obtained at the conclusion of training in Experiment 4. These results suggest that some characteristics of automatic processing had begun to emerge at this point in training with the complex rule-based alphanumeric task. Future research should therefore examine the effects of more extensive training with this complex task, and should also include a higher level of memory load than used here to provide a possibly more sensitive test of CM vs hybrid VM differences.

Experiment 6 provided no evidence of a differential effect on CM or VM performance of transfer to a higher workload condition than had been previously trained. As noted above, the capability to evaluate any such differences was compromised by the modest differences in CM vs VM performance established during training. Future research with complex spatial pattern information should examine this transfer issue with the hybrid visual/memory search paradigm employed in Experiment 3. This work should also employ a more extensive transfer period than that used in the present experiment.

Finally, the last experiment in this series dealt with the issue of retention of static spatial pattern information representing classes of movement that must be processed by operators of some C2 systems. The results of this experiment demonstrated no reliable loss of CM performance over a 30-day retention interval. This finding has important implications for the capability to maintain automatic processing of static spatial information in memory search over the period tested, and should be extended to dynamic spatial pattern information and to complex alphanumeric information as well. Additional research should also be conducted to examine retention in a visual search paradigm

with these types of materials because the results of Fisk et al. (1990) suggest that the retention function in this paradigm may be different from that in the memory search paradigm used here.

IV. PROMPTING AS AN AID IN ACQUIRING COMPLEX SPATIAL PATTERN DETECTION SKILLS

As noted previously, extensive training is required before automatic performance can be realized with the type of high-performance skills required of Air Force C2 operators. Schneider (1985), for example, defined high-performance skills as those requiring in excess of 100 hours of training, and noted that training programs for these skills often have very high failure rates.

There is little evidence to indicate that difficult skills can be quickly automatized using present techniques. Nevertheless, the high cost of extended training in complex skills, such as represented by the simulated weather pattern detection task described in Experiments 2 and 6, stresses the need to explore procedures that might potentially reduce the required training time.

The choice reaction time paradigm is a well-defined laboratory paradigm that is analogous to target detection procedures. If the usual choice reaction task is altered such that stimulus alternatives are markedly increased in number and complexity, then choice reaction closely parallels the target detection found in the simulated weather pattern detection task. Wickens (1984) described factors affecting choice reactions, and these can also be related to target detection. Major influences on choice reaction/target detection include the following classifications: (a) amount of training provided; (b) stimulus discriminability, in particular the similarity of the targets and distractors; (c) stimulus-response compatibility, the learned or naturally occurring correspondence between stimulus and response;

and (d) number of stimulus alternatives, and amount of information processed as revealed by the Hick-Hyman relationship (Hick, 1952; Hyman, 1953).

For at least simple detections of targets versus noise, the interrelated requirements of training trials, information processing, and stimulus discriminability could easily be satisfied for highly discriminable as opposed to poorly discriminable targets. Therefore, given compatible stimulus-response channels, high rates of target detection would be expected.

Based upon the above considerations, a training model was developed which places the major emphasis in target detection training on the variable of target enhancement. Altering the detectability of targets as a training function compresses the problem of how to train subjects to detect targets to a more focused problem of how to shift from artificially enhanced targets but still maintain the detectability and detection rate shown under the aided conditions. In effect, given easily noticed targets and compatible response methods, the task of training becomes one of how to maintain the already achieved levels of performance after the target prompting is removed.

From a cybernetic point of view (e.g., Ashby, 1956; Sommerhof, 1974), placing major emphasis on target aiding could be described as transforming the variety represented in methods and techniques of normal training procedures into the variety of target modulations, to bring about the same goal of a highly trained subject. The experimental question from this perspective is whether the time rate of information transfer between the task essentials and subjects-acquired abilities would be increased with use of this training strategy, thereby permitting more training in less training time or improved skill in the same time.

To initiate some evaluation of target-based training, a modification was made to the software controlling the simulated weather pattern detection task researched in Experiments 2 and 6 of this report. A modified experimental program (MXP) was implemented for AFHRL by SRL, Inc. to provide a number of elementary methods for prompting the detection of a target's occurrence on the search display. These features included controls that were designated (a) target intensity, which brightens target pixel intensity in relative units ranging from 0 to 64,000; (b) noise intensity, which brightens noise pixels from 0 to 64,000; and (c) auditory volume, which provides tone pulses concurrent with target pixels in a volume range ranging from 0 to 250 in relative units.

The features of target intensity, noise intensity, and auditory volume also permitted control for either incrementing or decrementing the settings automatically after each training trial or trial block. Prompting could be incremented, or faded away, in linear steps throughout the training session. No provisions were installed for nonlinear changes, for reversing direction of the linear changes as a function of trials, for adaptive control of target intensity, or for rapidly switching between types of stimulus enhancements.

The decrementing function was incorporated into the system because it was hypothesized that prompting, if not removed during training, would be deleterious to the learning process. Prompts not properly reduced within training could easily promote a dependency upon the prompted features of the target, and thereby preclude a trainee's searching for and detecting the nonprompted features as they exist in the normal state.

A simplified mode of response was installed to optimize the stimulus-response compatibility feature referred to above. To implement a compatible response mode, the visual display of the weather detection trainer was marked off in quadrants and

referenced to a four-key arrangement of keys on the computer keyboard. The design principle was one of expediting the response portion of the target detection task so that this aspect of the training would not be a hindrance to rapid reporting of detected targets. This response mode was essentially the same as that used in Experiment 3, and was expected to provide increased target-related processing time for skill acquisition.

Experiment 8
An Initial Evaluation of Perceptual Prompting as an Aid in the Development of Target Detection Skill: Effects of Combined Auditory and Visual Prompts to Target Location

Purpose

The purpose of this experiment was to evaluate the effects in the simulated weather pattern detection task of providing both visual and auditory prompts that were synchronized in time with the appearance of individual target elements. The visual prompt also provided information concerning the exact location of the target on the visual display.

The primary aim of the experiment was to assess evidence for the advantage of prompting using the MXP system in relation to the performance variables of target detection rate, mean search time per trial, and correctness of detection performance. The scope of this first study did not include an assessment of the value of prompted training upon subsequent performance without prompting.

A second purpose of the present experiment was to obtain an initial evaluation of the MXP system which (a) provided software control of the experimental target and target-related enhancements, and (b) formed the basis of the training experiments discussed below.

Method

Subjects. Subjects were 12 University of Dayton students. They were given one unit of research credit toward the fulfillment of the research requirement of their introductory psychology course.

Apparatus. The experiment used an Apple Macintosh IIx computer and a 19-inch, high-resolution PCPC color monitor. Responses were made on standard numeric keys placed on the right side of an extended keyboard. Each of four keys was coordinated to one of four designated quadrants of the CRT display according to the following scheme: (a) key 7, upper left quadrant; (b) key 9, upper right quadrant; (c) key 1, lower left quadrant; and (d) key 3, lower right quadrant. The right side of the keyboard was covered except for openings for the four numeric keys. Auditory prompts were presented through the built-in speaker of the computer. All timing was performed by the software program. Time values were recorded in units that approximated actual time and were consistent across the experimental conditions.

Procedure. Subjects were instructed in the same general type of weather detection pattern task described in Experiment 3. This task required that the subjects view a search display divided into adjacent quadrants. Background noise was present in all four quadrants, and one of the quadrants included the critical weather pattern. Subjects were required to press a key on the extended keyboard that corresponded to the quadrant containing the target pattern. Response time was measured from the appearance of the target on the display until the subject pressed one of the designated keys on the keyboard.

In the initial instructions and practice trials, subjects were familiarized with the general task, the keyboard response requirements, and the sequence of stimulus presentations. The latter included descriptions of the feedback provided with each

trial, which indicated whether the subject's response, or lack of response, was a "hit," a "miss," or a "failure to respond." Before training, each subject was given six practice trials. The first trial used target prompting with target pixel intensity set at 64,000 units and background noise pixel intensity set at 32,000. On the remaining five trials of practice, both target and noise intensities were set at 64,000. All subjects were encouraged to quickly search for, identify, and report the quadrant within which the target appeared by pressing one of the four keys coordinated to quadrants on the CRT.

In the training session, six subjects received 32 trials of training using a sequence of 8-trial blocks which began with a prompted block. The remaining six subjects received a sequence that began with a non-prompted block. Prompted and non-prompted blocks were alternated for each group.

There was an identical sequence of target locations programmed to appear in the various quadrants for both prompted and non-prompted training conditions. The only differences between the prompted and non-prompted conditions were that the prompted condition included an auditory pulse synchronized with the appearance of each target pixel on the CRT, and noise intensity was set at a value of 32,000 instead of 64,000. All other task-related conditions were equivalent.

Stimulus Materials. The MXP system was used to control the prompting variables. Conditions of training used the following prompts and task-related settings: (a) target pixel intensity: 64,000; (b) noise intensity: 32,000; (c) auditory volume: 40; (d) trace decay: 4,000; (e) noise level: 8; (f) refresh rate: 5; (g) target selected: 1; and (h) lag time: 1. The condition of non-prompted training used the same settings except for noise intensity, which was set at 64,000, and auditory volume, which was turned off.

Design. Three independent variables were included in the design: (a) prompting of target vs non-prompting of target, which represented a within-subjects variable; (b) number of sessions (back-to-back blocks of 16 trials) of continuous training, which also represented a within-subjects variable; and (c) sequence of prompted vs. non-prompted conditions, which represented a between-subjects variable used to control for effects of sequence of training conditions.

The independent variables were evaluated by means of three dependent variables: (a) target detection rate, (b) search time, and (c) percentage of correct detections. Target detection rate was a measure based upon the number of targets detected per minute of search time. Search time was defined as the time duration in seconds commencing with the appearance of the target on the display and continuing until either a response was made by the subject or a trial was terminated by a failure to respond. The measure of search time reflected the mean times of searches that ended in a target detection or hit, a miss, or a failure to respond. Percentage of correct detections reflected the number of hits compared to the combined number of hits, misses, and failures to respond.

Results

Target Detection Rate. Mean target detection rate in the weather pattern detection task as a function of prompted vs non-prompted training and sessions is illustrated in Figure 40. The means shown in Figure 40 are based on correct detections by subjects. As shown in the figure, prompted training (PT) vs non-prompted training (NPT) and training sessions had an effect upon target detection rate. Mean target detection rates were consistently higher for the PT condition compared to the NPT condition, and both conditions yielded higher target detection rates as a function of practice.

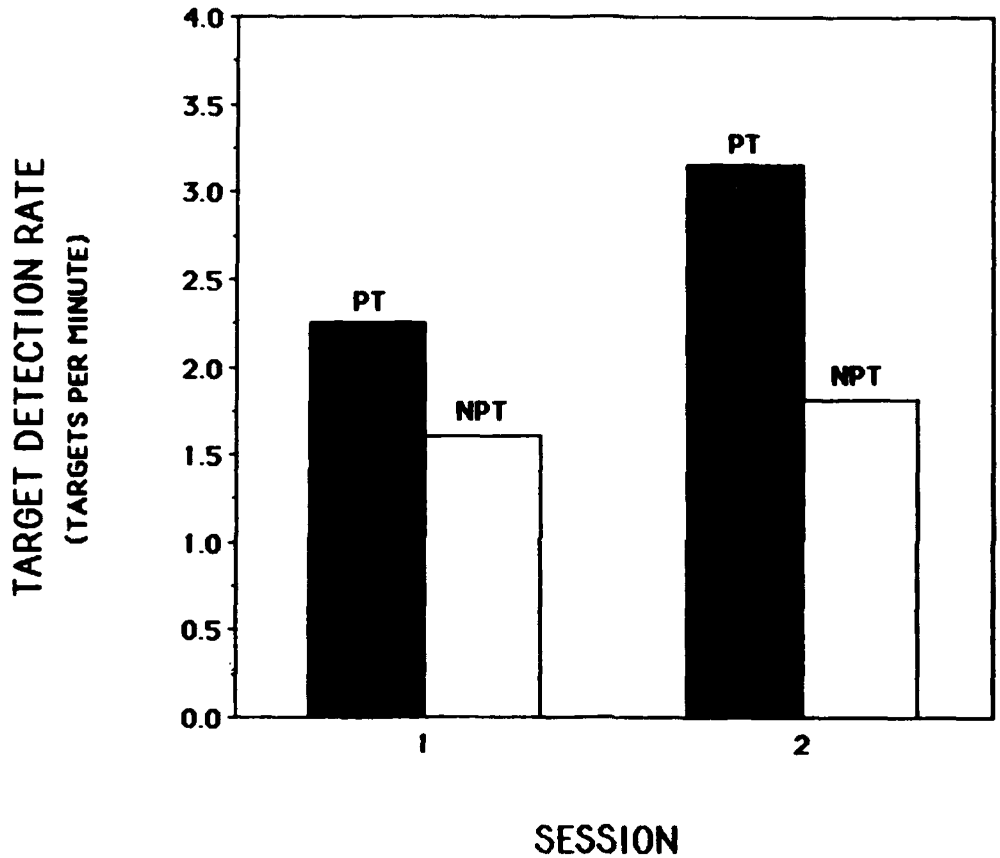

Figure 40. Mean Target Detection Rate as a Function of Type of Training and Session.

A 2-x-2-x-2 ANOVA was performed on the measures of target detection rate to analyze the effects of two types of training (PT vs NPT), two sequences of training condition (PT, NPT, PT, NPT vs NPT, PT, NPT, PT), and two sessions of training (two back-to-back sessions of 16 trials each). Type of training and training sessions were within-subject factors whereas sequence of training condition was a between-subjects factor. This analysis showed that the effects of type of training [$F(1,10) = 22.93$, $p < .01$] and training sessions [$F(1,10) = 17.58$, $p < .01$] were reliable. The effect of sequence of training conditions, a control factor, was not significant [$F(1,10) = .16$, $p > .05$]. The interaction of type of training with training sessions [$F(1,10) = 5.23$, $p < .05$] was the only significant interaction.

The effect of PT in producing higher rates of target detection is consistent with the expectation that brighter-appearing elements would stand out in a context of dimmer-appearing elements. Additionally, the tone pulses sounding with each appearance of a target pixel subjectively appeared to foster a more intense search effort, once it was made definite that a target was currently appearing on the search display.

The effect of sessions of training is consistent with the expected effect of practice upon time required to detect targets in similar search tasks. The significant interaction found between sequence of training condition and session of training is interpretable from Figure 40. The difference between the PT condition and the NPT condition in Session 2 is greater than in Session 1. Apparently, prompted training was differentially more improved in target detection rate as a function of practice than was non-prompted training.

Search Time. Mean time of target search is shown in Figure 41 as a function of the PT/NPT conditions and training sessions. As depicted in the figure, the task conditions of PT/NPT and sessions had an effect upon mean search time. Mean search time

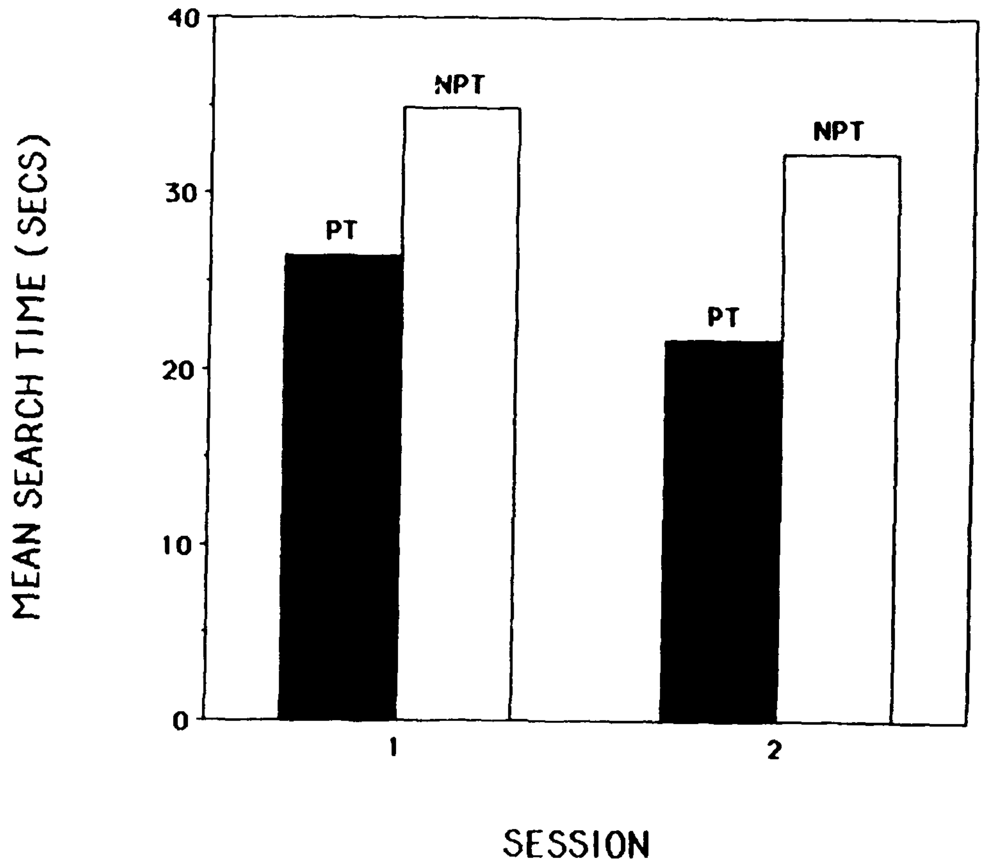

Figure 41. Mean Time of Target Search as a Function of Type of Training and Training Session.

was shorter for the PT compared to the NPT conditions, and was also shorter as a function of training session.

A 2-x-2-x-2 ANOVA was performed on the measures of mean search time to assess the effects of two types of training (PT vs NPT), two sequences of training condition (PT, NPT, PT, NPT vs NPT, PT, NPT, PT), and two sessions of training (two back-to-back sessions of 16 trials each). Once again, type of training and training sessions were within-subject factors whereas sequence of training condition was a between-subjects factor. This analysis demonstrated that the effects of type of training [$F(1,10) = 20.83$, $p < .01$] and training sessions [$F(1,10) = 12.45$, $p < .01$] were significant. The effect of sequence of training conditions, a control factor, was not significant [$F(1,10) = .006$, $p > .05$]. None of the interactions were significant.

Because responses to targets were largely correct detections (approximately 95 percent of the responses resulted in correct detections of target location), it would be expected that mean search time would closely parallel target detection rate, with shorter search times being associated with higher target detection rates. Thus, the interpretations offered above to the analysis of target detection rate would also generally apply to the findings related to type of training and sessions of training, using the measure of mean search time. As shown in Figure 41, mean search time was reliably shorter for the PT condition vs the NPT condition, and was reliably shorter for both PT and NPT as a function of practice.

Accuracy of Responding. Figure 42 shows the percentage of correct detections as a function of PT/NPT conditions and training sessions. As displayed in the figure, percentages of correct detections were consistently high across both training conditions and sessions of training.

A 2-x-2-x-2 ANOVA was performed on the measures of correct

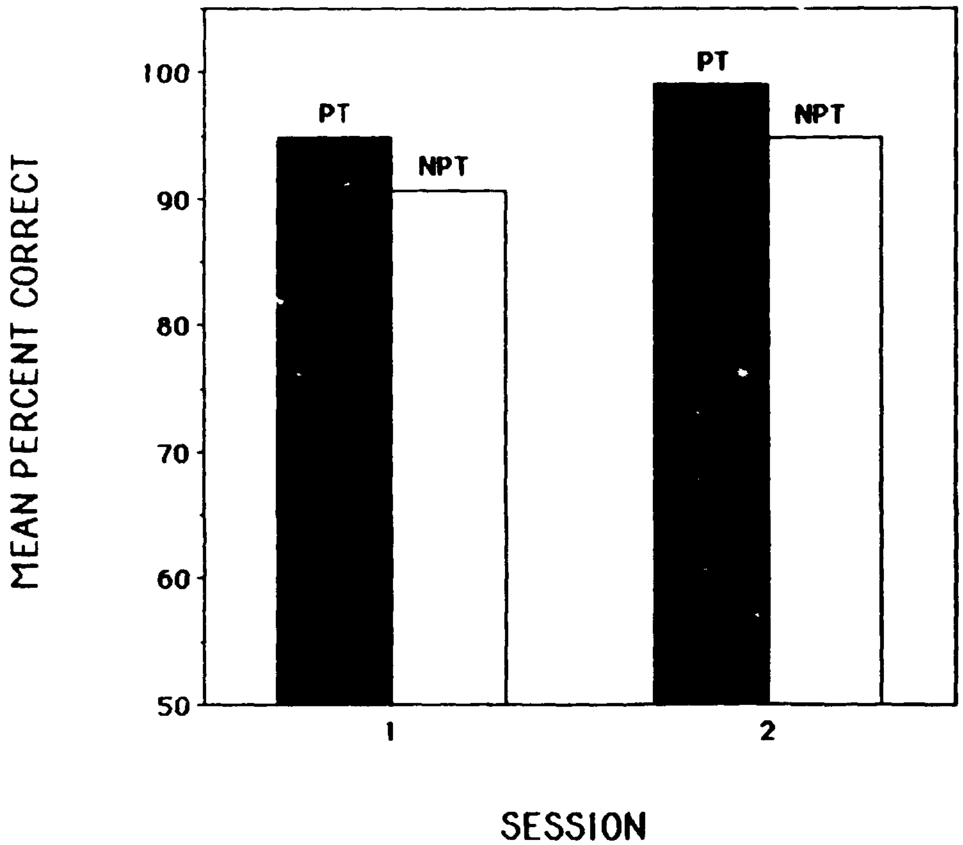

Figure 42. Mean Percent Correct as a Function of Type of Training and Training Session.

detection to analyze the effects of two types of training (PT vs NPT), two sequences of training condition (PT, NPT, PT, NPT vs NPT, PT, NPT, PT), and two sessions of training (two back-to-back sessions of 16 trials each). As in previous analyses, the sequence of training was a between-subjects factor whereas type of training conditions and training sessions were within-subject factors. None of the factors or interactions of factors reached statistical significance. The high detection rates and the general lack of response error found in this study probably reflect the use of relatively low values of background noise level, refresh rate, and the restriction of targets to a single target.

Discussion/Recommendations

From the above findings, it is clear that the higher target detection rate and shorter mean search time both confirm the assistance of target prompting in this type of task. A very large number of possible combinations of tone and pixel prompting are possible with the MXP system, and would require many separate evaluations using traditional methods. However, given that prompting is effective, it does provide the basis for investigating the usefulness of this training procedure for transfer to a subsequent task that will not have target enhancement available.

During the course of the study, it became evident that a marked time savings in the basic evaluation of different types of prompting would be obtained if the MXP system permitted a programmable change in type and level of prompting with each trial. The ability to randomly sample different prompt types and levels would permit a within-subjects evaluation. This ability would eliminate much of the requirement for numerous subjects and a larger set of trials to stabilize the response data. With trial-by-trial variations, many different types of cueing could be assessed at many levels of magnitude for the same subject. It

would also provide an efficient means to determine if a certain magnitude of aiding produced any detectable difference.

Experiment 9
An Initial Evaluation of Target Detection Performance Without Prompting Following Training with Prompting

Purpose

The key purpose of the present experiment was to explore the effects of training under prompted target conditions upon subsequent performance under non-prompted test conditions. Additionally, this experiment served to gather further information concerning prompted performance, especially that based upon decremented prompting. The experiment also provided the opportunity to make additional observations related to possible modifications to the MXP system.

Prompting would be expected to incur a dependency upon such aiding as a function of trials in training under prompted conditions. The present research was designed as an initial assessment of training using the decremented prompting feature of the MXP system. It was assumed that decremented prompting might alleviate the problem of dependency upon detection aids but still accrue greater overall benefits in training.

Method

Subjects. Subjects were 12 University of Dayton students. They received one unit of research credit toward the fulfillment of research requirements of their introductory psychology course for each hour of participation.

Apparatus. The experiment used the same Apple Macintosh IIx computer and high-resolution, 19-inch PCPC color monitor as used

in Experiment 8. Responses were made on the numeric keys located on the right side of an extended keyboard. Each of four keys was coordinated to the four quadrants of the CRT display: (a) key 7, upper left quadrant; (b) key 9, upper right quadrant; (c) key 1, lower left quadrant; and (d) key 3, lower right quadrant. The right side of the keyboard was covered except for openings for the four numeric keys.

Procedure. Subjects were instructed in the same basic type of weather detection pattern task reported earlier. This task required that the subjects view a search display divided into adjacent quadrants. Background noise was present in all four quadrants, and one of the quadrants included the critical weather pattern. Subjects were required to press a key on the extended keyboard that corresponded to the quadrant containing the target pattern. Response time was measured from the appearance of the target on the search display until the subject pressed one of the designated keys on the keyboard.

In the initial instruction and practice session, subjects were instructed in the general weather pattern detection task, the four-key response requirements for reporting detected targets, the sequence of stimulus presentations, and the feedback displayed after each trial. This feedback indicated whether the response or lack of response was a "hit," a "miss," or a "failure to respond." Subjects were guided through eight trials of practice. For six of the subjects, designated the prompted group, the target intensity on the first practice trial was set at 64,000 and the noise intensity was set at 16,000. This was done to demonstrate the nature of the visual prompting that would be used during the actual training sessions of the experiment for this group. In the subsequent seven practice trials, both target and noise intensities were set at 64,000. For the remaining six subjects, designated the non-prompted group, both target and noise pixel intensity were set at 64,000 on all practice trials. Every subject was encouraged to quickly search for, identify, and

report the quadrant within which the target appeared, by pressing one of the four keys coordinated to quadrants on the CRT.

Over three daily sessions of 48 trials, the prompted group received training using a decremented prompting procedure. Prompting consisted of the noise intensity being set at a lower level than target intensity. Prompting was decremented by starting noise intensity at a level of 16,000 and then increasing the noise intensity in steps of 1,200 units after each trial. Noise levels started with a stimulus value of 16,000 on Trial 1 of each session and ended with a value of 64,000 on Trial 40 of each session. On Trials 41 to 48 of each session, both target and noise intensities were maintained at 64,000.

The non-prompted group received non-prompted training conditions over the three daily sessions of 48 trials. For this group, the noise and target pixel intensities were maintained at a level of 64,000 on all trials of all sessions. Trials 41 to 48 of each session were designated test trials for both the prompted and non-prompted groups.

Target locations were randomly assigned on each trial of each session. However, all subjects received the same target locations and noise patterns on corresponding trials of each session.

Stimulus Materials. The MXP system was used to control the prompting variables. The following settings were used in the basic weather pattern detection task: (a) noise level: 22; (b) refresh rate: 5; (c) lag time: 1; (d) trace decay: 4,000; and (e) target selected: 1. The following settings related to the prompting variable were used: (a) noise intensity start: 16,000; (b) noise intensity delta: +1,200; and (c) target intensity: 64,000.

Design. Three independent variables were included in the design: (a) decremented pixel prompting of targets vs non-prompting of targets; (b) three repeated sessions of the identical 48 trials of training over 3 days; and (c) four blocks of 10 training trials, followed by one block of 8 test trials. The first variable was a between-subjects variable, whereas the latter two were within-subjects variables. Six subjects received decremented prompting in three repeated sessions over 3 days, whereas the remaining six subjects received non-prompted training in three repeated sessions over 3 days. Except for the decremented prompting, the non-prompted and prompted subjects had identical task conditions.

Three dependent variables were related to the design: (a) mean target detection rate; (b) mean search time based upon hits, misses, and failures to respond; and (c) mean percentage of correct detections.

Results

Target Detection Rate. Mean target detection rate in the weather pattern search task, as a function of prompted vs non-prompted targets, is illustrated in Figure 43. The means shown represent the mean target detection rate for each of the training blocks and the test block, after collapsing trial blocks across the three daily sessions. The values are based on correct detections by subjects. As shown in the figure, task conditions of PT/NPT and trial blocks had a clear effect upon target detection rate. Mean target detection rates were initially higher for the prompted condition compared to the non-prompted condition. For the non-prompted subjects, mean target detection rates increased throughout the training. For the prompted subjects, on the other hand, mean detection rates decreased from a high value in the early highly prompted trial blocks to a value comparable to the non-prompted subjects in the later test trials.

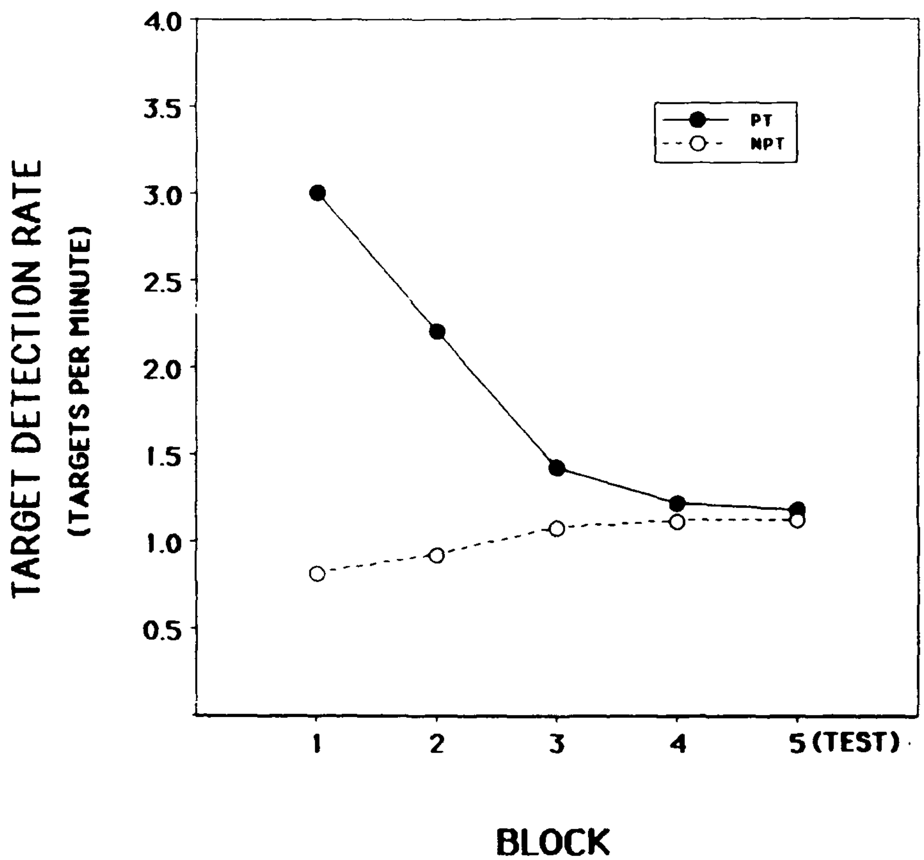

Figure 43. Mean Target Detection Rate as a Function of Type of Training and Training Session.

A 2-x-5 ANOVA was performed on the measures of target detection rates to analyze the effects of two types of training (PT vs NPT) and five blocks of trials. The former was a between-subjects factor and the latter a within-subjects factor. The first four blocks consisted of 10 trials of training, whereas the last block included 8 trials that served as a test condition of non-prompted trials. The analysis revealed a significant effect for type of training [$F(1,10) = 11.66$, $p < .05$]. A significant effect for trial blocks [$F(4,40) = 22.58$, $p < .01$] was also found, as was a significant interaction of type of training x trial blocks [$F(4,40) = 45.32$, $p < .01$].

A 2-x-3 ANOVA was conducted on target detection rates during the block of test trials to analyze the effects of the two types of training (PT vs NPT) and three sessions of test trials. This analysis found type of training (PT vs NPT) did not reach significance, but the sessions effect was found significant [$F(1,10) = 6.76$, $p < .05$]. The interaction was not statistically significant. Figure 44 shows the increase in target detection rates for both PT and NPT subjects as a function of performance in test trials over the three sessions. It supports the interpretation that performance was improving for all subjects as a function of sessions of training, but does not support the hypothesis that target-enhanced training is an advantage.

Search Time. Mean time of target search is shown in Figure 45 as a function of the PT/NPT conditions and trial blocks. The means shown represent the mean search time for each of the training blocks and the test block after collapsing trial blocks across the three sessions. As depicted in the figure, task conditions of PT/NPT and sessions had an effect upon mean search time. Mean search time was initially shorter for the PT vs the NPT condition but increased throughout the trial blocks, as prompting was reduced, to become comparable to the NPT condition during the test block.

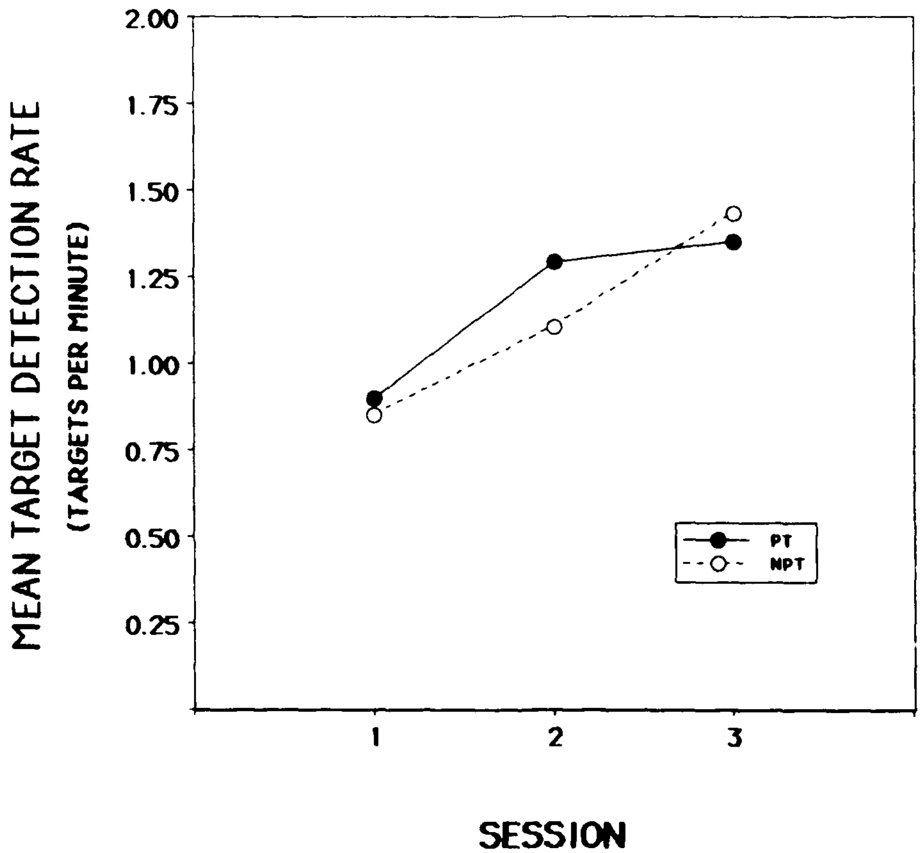

Figure 44. Mean Target Detection Rate in Test Trials as a Function of Type of Training and Training Session.

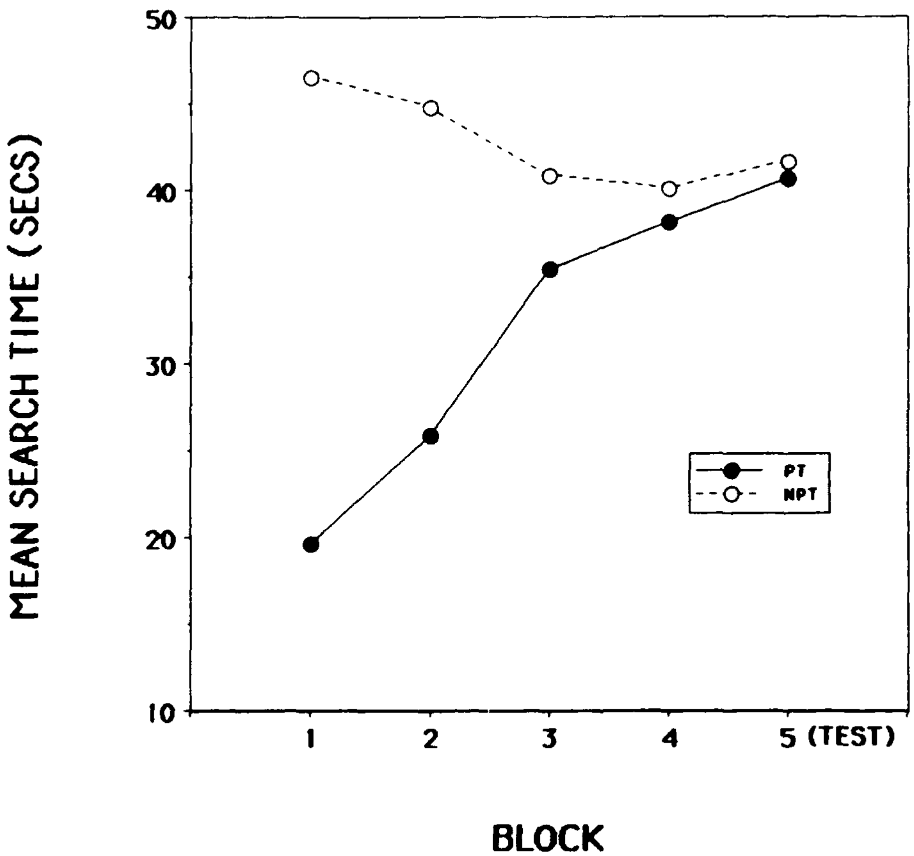

Figure 45. Mean Time of Target Search as a Function of Type of Training and Trial Block.

A 2-x-5 ANOVA was performed on the measure of search time to analyze the effects of two types of training (PT vs NPT) and five blocks of training. The first four blocks were 10 trials each and the last block was 8 trials serving as a test condition. PT vs NPT was a between-subjects factor and trial blocks was a within-subjects factor. The analysis revealed significant effects for type of training [$F(1,10) = 7.20$, $p < .05$] and trial blocks [$F(4,40) = 10.15$, $p < .01$], and a significant type of training x trial blocks interaction [$F(4,40) = 33.24$, $p < .01$]. Figure 45 shows that as the prompting was removed, mean search time for prompted subjects increased with each block of trials. Non-prompted subjects showed a trend of decreasing search time across trial blocks. The different levels of search time for the two training conditions describe the effect of type of training, whereas the different directions of the change of levels relate to the interaction found between type of training and trial blocks. The effect of trial blocks on mean search time can be interpreted as related to the fact that mean search time increased more rapidly for prompted subjects than it decreased for non-prompted subjects. Thus, the overall effect of trial blocks was an increase in mean search time.

The critical factor of performance in test trials was the subject of a second 2-x-3 ANOVA, which analyzed the effect of PT vs NPT as a function of blocks of test trials across three sessions of training. Type of training was the between-subjects factor and sessions served as the within-subjects factor. The analysis revealed that only sessions produced a reliable effect on mean search time [$F(2,20) = 4.06$, $p < .05$]. The effects of sessions and NPT vs PT conditions are depicted in Figure 46, which shows that performance improved across sessions of training. However, as with target detection rate, the effect of prompting on mean search time revealed an effect limited to the prompted trials. With the removal of prompting during the test trials, mean search time became equivalent under the two training conditions.

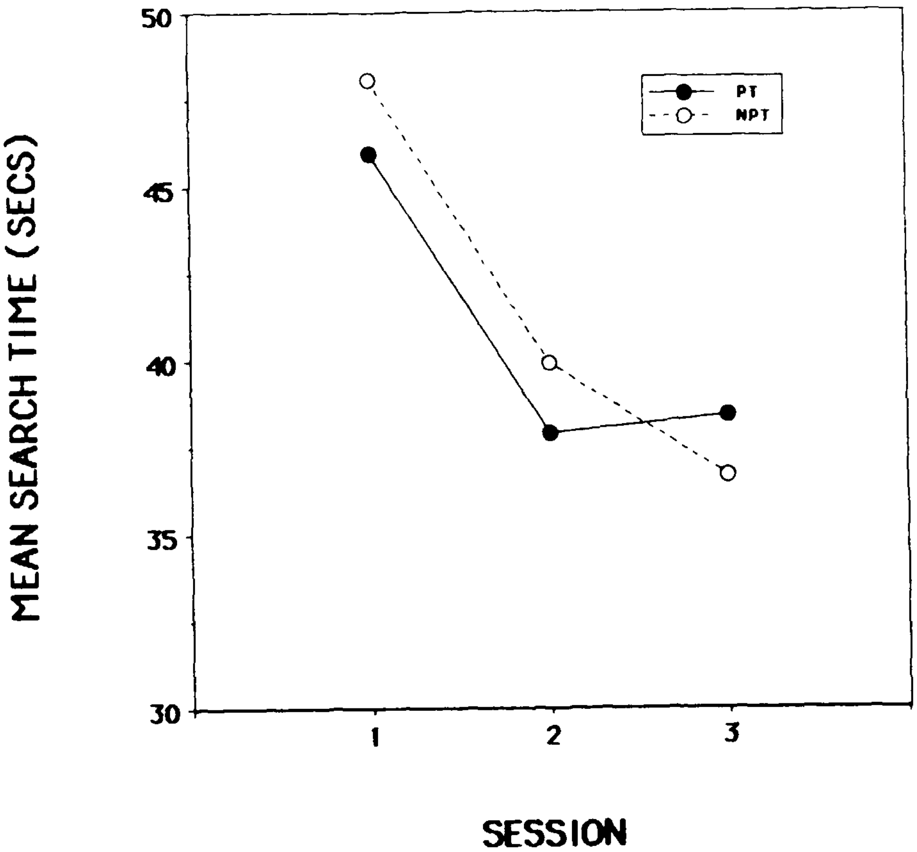

Figure 46. Mean Time of Target Search in Test Trials as a Function of Type of Training and Training Session.

Accuracy of Responding. Figure 47 shows mean percentage of correct detections as a function of trial blocks within sessions. Initially under high prompting, the prompted group made a greater percentage of correct detections than the non-prompted group. However, as training continued and prompting was lowered in level, the mean percentages of correct detections between PT and NPT became more alike. A 2-x-5 ANOVA was carried out to evaluate the effect of type of training and trials upon mean percentage of correct detections. The between-subjects factor was type of training (PT vs NPT) and the within-subjects factor was trial blocks (after collapsing across sessions). The analysis showed that type of training [$F(1,10) = 7.47$, $p < .05$] and the interaction of type of training x trial blocks [$F(4,40) = 10.02$, $p < .01$] were statistically reliable. As shown in Figure 47, the different levels of correct detections between PT and NPT account for the effect of type of training. The interaction effect is revealed in the tendency for PT to decline in correct detections and NPT to increase in correct detections.

In a second 2-x-3 ANOVA, percentage of correct detections was analyzed with respect to test trials across the three sessions of training. This analysis revealed only a main effect of sessions [$F(2,20)= 8.35$, $p < .01$]. Figure 48 depicts the change in correct detections as a function of sessions and PT vs NPT training conditions. Just as with the measures of target detection rate and search time, PT was initially superior in percentages of correct detections, but this initial superiority declined across sessions and was eventually eliminated.

Discussion/Recommendations

All three performance measures show essentially the same pattern of results. Results indicate that prompting during training was associated with superior performance under prompted test conditions but failed to significantly affect performance

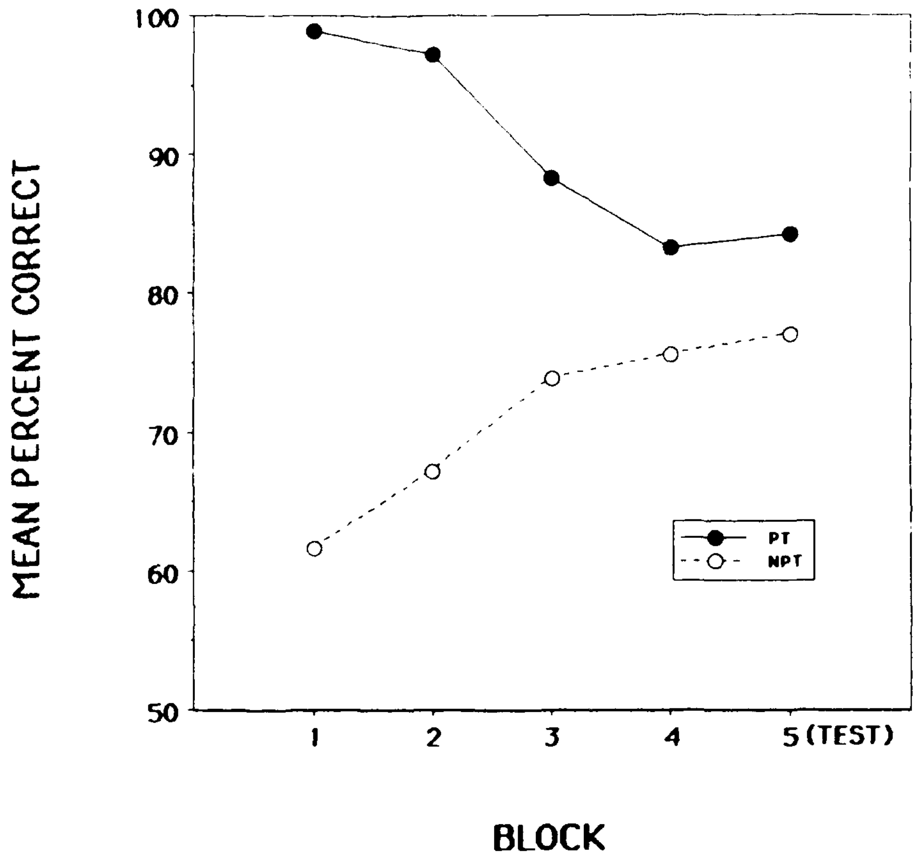

Figure 47. Mean Percent Correct as a Function of Type of Training and Trial Blocks Within Sessions.

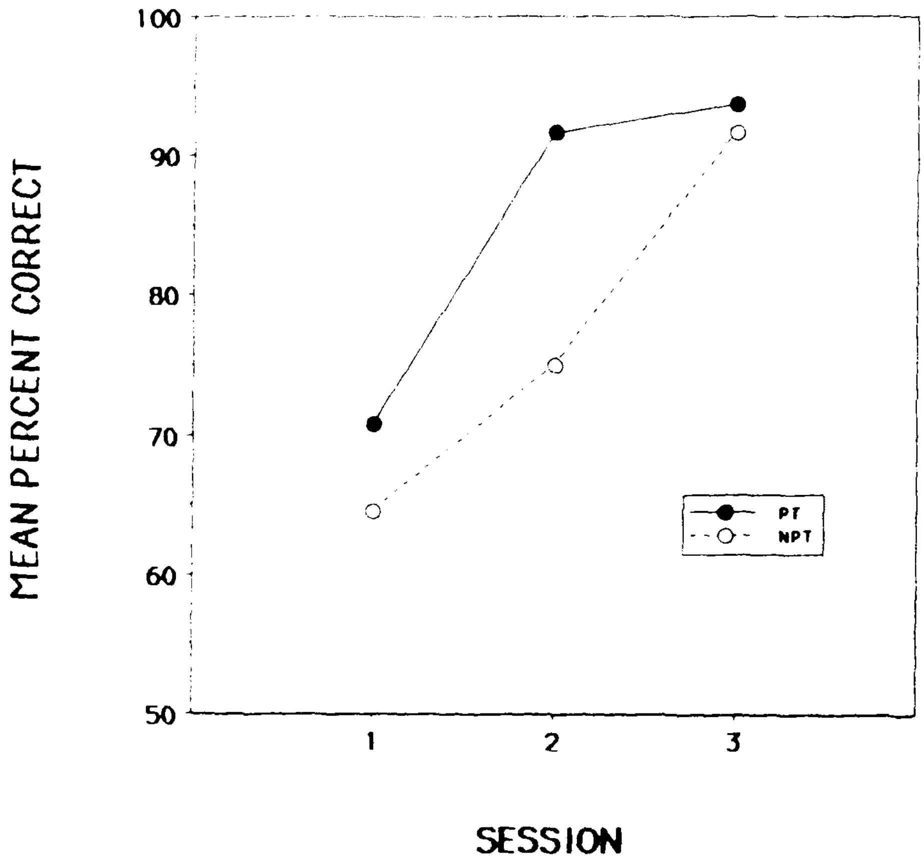

Figure 48. Mean Percent Correct in Test Trials as a Function of Type of Training and Training Session.

during test trials in which prompting was removed.

Based upon the shorter search times with prompted training procedures, it is recommended that the MXP system be modified to permit new targets to appear immediately after a response is made. Coupled to this change should be the installation of a nonlinear decrementing procedure to permit a greater variety in the decrementing function. Both changes are based on the need to allow more targets to be detected per unit search time, while providing for flexible programming of different patterns of reduction in prompts.

Experiment 10
The Effects of Target Prompting on Target Detection as a Function of Time-Based Training

Purpose

The purpose of this experiment was to evaluate the effects on target detection performance of providing enhanced visibility of targets relative to non-targets under conditions that differed from those used in the previous experiments. The central issue was the same as that investigated in Experiment 9, and concerned the effects of prompted training on performance under non-prompted conditions that occurred subsequent to training. The experiment manipulated the decrementing of prompting in sessions instead of trials. Also, the task difficulty level was higher than in Experiment 8. It was judged important in these initial studies to make a comparison between prompted vs non-prompted training with a level of task difficulty considered high for beginning trainees in the weather pattern detection task.

An additional objective of this experiment was to explore the use of time-based training in the weather pattern detection task. The time-based training concept was based upon the expectation that prompted subjects might benefit from a possibly

greater number of training trials that could be completed in the same training time allocated to non-prompted subjects.

Method

Subjects. Subjects were 10 University of Dayton students. They were paid $4.00 per hour for their participation. In addition, subjects were awarded a bonus payment of $1.00 per hour for appearing on time for each of the scheduled experimental sessions.

Apparatus. The experiment used the same Macintosh IIx computer and high-resolution, 19-inch PCPC color monitor as that used in Experiments 7 and 8. Responses were made on the numeric keys located on the right side of an extended keyboard. Each of four keys was coordinated to the four quadrants of the CRT display: (a) key 7: upper left quadrant; (b) key 9: upper right quadrant; (c) key 1: lower left quadrant; and (d) key 3: lower right quadrant. The right side of the keyboard was covered except for openings for the four numeric keys. Auditory prompts were presented through the built-in speaker of the computer.

Procedure. Subjects were instructed in the same basic type of weather pattern detection task reported earlier. This task required that the subjects view a search display divided into quadrants adjacent to one another. Background noise was present in all four quadrants, and one of the quadrants included a target weather pattern. Subjects were required to press a key on the extended keyboard that corresponded to the quadrant containing the target pattern. Response time was measured from the appearance of the target on the search display until the subject pressed one of the designated keys on the keyboard.

In the initial instruction and practice session, subjects were familiarized with the general weather pattern detection task, the keyboard response requirements, and the sequence of

stimulus presentations. Subjects were also familiarized with the post-trial feedback system that indicated if the subject's response or lack of response was a "hit," a "miss," or a "failure to respond."

Subjects were guided through 16 practice trials using each of four targets. The targets selected were numbers 1, 2, 7, and 8 in the MXP system. Subjects were encouraged to quickly search for, identify, and report via keyboard response the demonstrated targets.

In the first of four training sessions, the five subjects performing the task under PT conditions had target intensity set at 64,000, whereas the five subjects serving under NPT conditions used target intensity settings of 32,000. Prompted subjects--in their first session only--also received auditory prompting during the first 30 training trials.

The non-prompted group maintained the same target intensity values over the four training sessions. The prompted subjects received decrements in target pixel intensity on each of three daily sessions following the first session. On Day 2, prompted subjects received targets set at 48,000 intensity units; on Day 3, the targets were set at 40,000 units; and on Day 4, the target intensity was set at a level of 32,000 units. The background noise intensity level for all subjects was maintained at 32,000 units across all sessions.

Target locations were randomly assigned by the MXP system for each trial on the first session. Identical sequences of target and noise patterns were then repeated in each of the three subsequent sessions.

Each subject's training time per session was monitored and limited to 50 minutes. After the first 25 minutes of training,

subjects received a 5-minute break followed by an additional 25 minutes of training.

Stimulus Materials. The MXP system, previously described above, was used to control the displayed noise and target pixels making up the subject's search field. The following conditions were programmed: (a) one of four targets was used on each trial; (b) noise level: 22; (c) trace decay: 1,000; (d) refresh rate: 10; (e) noise intensity: 32,000; and (f) lag time: 1. For the non-prompted conditions, target intensity was set at 32,000. For prompted subjects, target intensity settings varied over the sessions with the following associated session and intensity values: (a) Session 1: 64,000; (b) Session 2: 48,000; (c) Session 3: 40,000; and (d) Session 4: 32,000.

Design. Two independent variables were represented in the design: (a) target prompting vs no target prompting which represented a between-subjects variable; and (b) training sessions, which represented a within-subjects variable. Each subject participated in four 50-minute training sessions. Target aiding consisted of pixel prompting, and four steps of decrementing magnitude of prompt were employed across the four training sessions. In addition, 30 trials of decrementing tone prompts were used in the first 30 trials of the first training session. Five subjects received prompted training, and five subjects received non-prompted training.

Four dependent variables were related to the design: (a) target detection rate; (b) mean search time per session, based upon hits, misses, and failures to respond; (c) number of correct detections; and (d) trials completed.

Results

Target Detection Rate. Mean rate of target detection in the weather pattern search task as a function of prompted vs non-

prompted targets and sessions is illustrated in Figure 49. The means shown are based on correct detections by subjects. As shown in the figure, PT vs NPT and sessions had an effect upon target detection rate. Mean target detection rates during the early sessions of training were higher for the prompted subjects compared to those for the non-prompted subjects. However, target detection rates for prompted subjects fell below those for the non-prompted subjects during the final session.

A 2-x-4 ANOVA was performed on the measures of target detection rates to analyze the effects of two types of training (PT vs NPT) and four sessions of training. Type of training was a between-subjects factor, whereas training sessions was a within-subjects factor. The only significant effect demonstrated by this analysis was the type of training x sessions interaction [$F(3,24) = 4.66$, $p < .05$]. This interaction appears to be represented in Figure 49 as an initial advantage of target detection performance for the prompted subjects. A separate *t*-test applied to the mean scores based on the fourth or test session found no support for the existence of a significant difference between responses of subjects trained with prompted targets compared to those trained without prompts. As in Experiment 9 above, there was no indication of an advantage to prompting which lasted beyond the use of prompts.

Search Time. Mean time of target search is shown in Figure 50 as a function of the PT-NPT conditions and training sessions. As depicted in the figure, PT vs NPT had an effect upon mean search time during the early sessions of training. Mean search time was shorter for the PT condition compared to the NPT condition. Over the four sessions, mean search time increased for the prompted subjects but decreased for the non-prompted subjects. Both groups taken together first showed a relative decrease in search time, then a slight rise in search times as a function of sessions.

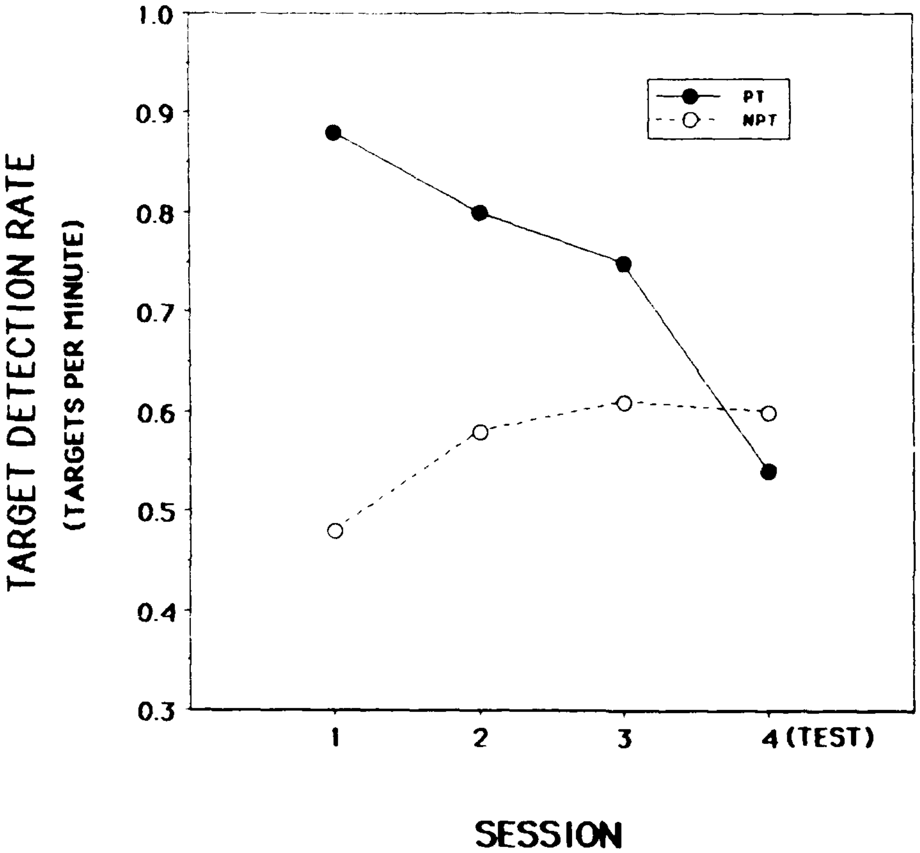

Figure 49. Mean Target Detection Rate as a Function of Type of Training and Session.

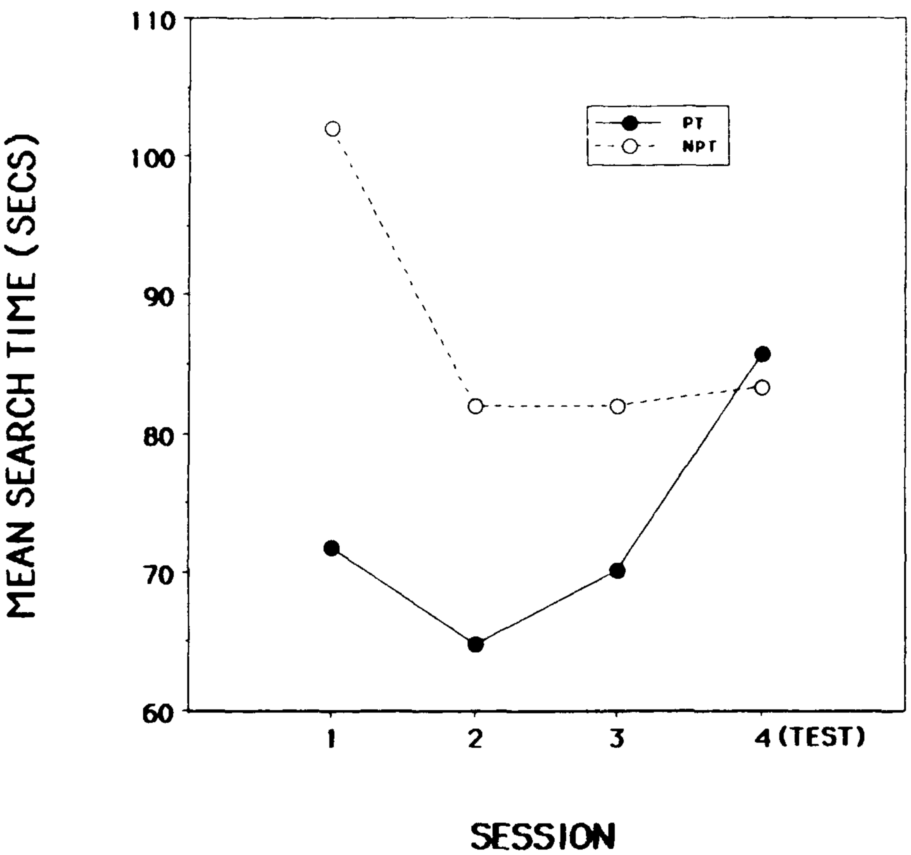

Figure 50. Mean Time of Target Search as a Function of Type of Training and Session.

A 2-x-4 ANOVA was performed on the measures of mean search time to statistically evaluate the effects of type of training (PT vs NPT) and training sessions. This analysis found that only the within-subjects factor of sessions [$F(3,24) = 3.14$, $p < .05$] and the interaction between type of training and sessions [$F(3,24) = 3.38$, $p < .05$] reached significance. This interaction effect is represented in Figure 50 by the lengthening of search time for prompted subjects over sessions at the same time that non-prompted subjects were exhibiting shorter search times. The effect of sessions is reflected in the groups taken together showing a differential level in search times as a function of sessions. A separate t-test was applied to prompted vs non-prompted mean search times in Session 4, the test session. No evidence was found that a significant difference existed between the mean search times of prompted vs non-prompted subjects in the test session. Again, as was the case in Experiment 9, performance became quite similar in mean search time as prompting was removed. The present result suggests that the effects of prompting do not endure subsequent to the prompted sessions. However, as in Experiment 9 above, the finding concerning search time supports a possible advantage of using prompted training. With prompting, it appears that it takes less time overall to achieve approximately equivalent performance to that achieved with non-prompted training.

Accuracy of Responding. Mean number of correct detections as a function of PT vs NPT and sessions is shown in Figure 51. The figure shows that number of correct detections varied as a function of prompting condition. Correct detections were more frequent in the prompted group as compared to the non-prompted group in the early sessions. By the last session, the advantage of prompting had disappeared and was reversing in direction.

A 2-x-4 ANOVA was performed on the measure of number of hits to analyze effects of PT vs NPT training and four sessions of training. Only the interaction between type of training and

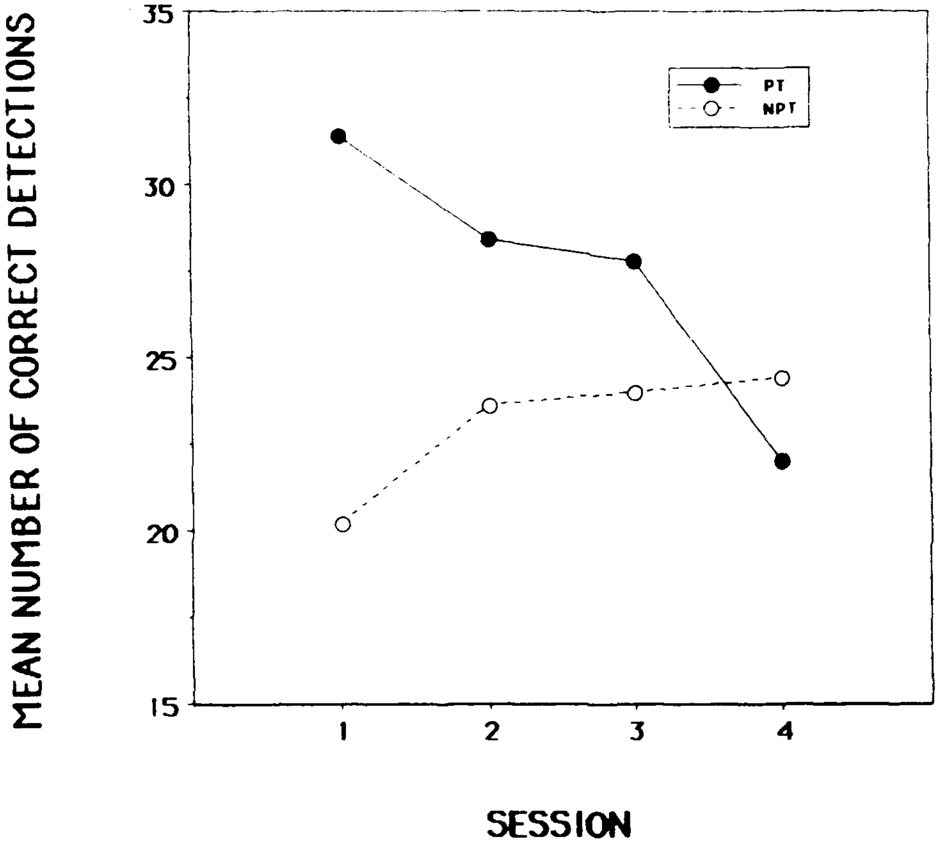

Figure 51. Mean Number Correct Detections as a Function of Type of Training and Session.

sessions proved to be significant [$F(3,24) = 4.46$, $p < .05$]. The interaction effect is evident in Figure 51, as illustrated by the decreasing number of correct detections in prompted subjects and the increasing number of correct detections by non-prompted subjects. A *t*-test was applied to the values for prompted vs non-prompted in the test session. The results of the analysis did not support the existence of a difference in the performance during the test session. As was the case with target detection rate and mean search time, the advantage of prompted training was not shown in the accuracy measure when prompting was removed. Differences in training under prompting vs non-prompting conditions were therefore not maintained during the test session.

Trials Performed. Mean number of training trials performed as a function of PT and NPT training in 50-minute training sessions is illustrated in Figure 52. As portrayed in the figure, prompted subjects performed a greater number of trials in the early sessions but then declined in the number of trials achieved when prompting levels were reduced. Non-prompted subjects achieved fewer trials than prompted subjects in early sessions but by Session 3, were approaching the performance of prompted subjects.

A 2-x-4 ANOVA was performed on the measure of number of trials achieved to analyze effects of type of training (PT vs NPT) and four sessions of training. The main effect of training sessions [$F(3,24) = 3.23$, $p < .05$] and the interaction between type of training and sessions [$F(3,24) = 3.14$, $p < .05$] proved significant. The sessions effect is apparent in Figure 52 as a sharp rise in number of trials performed in the early sessions, followed by a decline in later sessions. The interaction effect reflects the fact that prompted subjects started at a relatively greater number of trials in early sessions but declined in the later stages of training, while non-prompted subjects generally increased in trials performed. A *t*-test applied to the scores in the test session did not support a

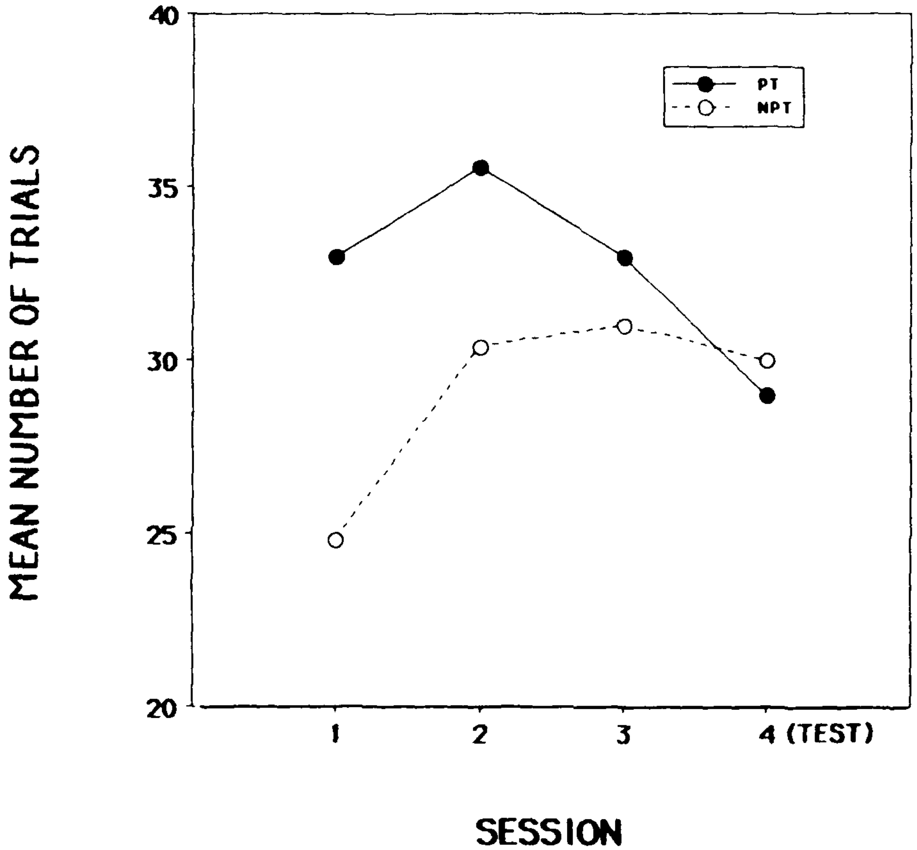

Figure 52. Mean Number of Training Trials Performed as a Function of Type of Training and Sessions.

hypothesis of a differential number of trials completed between the PT and NPT conditions. Again, as in other measures above, no support was found for a training benefit to derive from conditions of prompting.

Discussion/Recommendations

In Experiment 9 and in the present experiment, it is possible that the target-aiding levels used and the rate of decrementing of prompting may have nullified the role of the higher rates of target detection obtained via the target enhancements. Additional research should explore the use of different target-aiding levels and decrementing functions. The use of time-based training in the current experiment was not fully supported in the MXP training system. The present program does not allow a subject to stop practicing after a certain time period and then resume practice at that point in a subsequent session after the training system has been turned off. This precludes the use of slowly decrementing prompt levels across several daily sessions. It is highly recommended this feature be installed, so that prolonged training in prompted conditions can be supported with trial-by-trial decrements in prompt level.

General Discussion

The results across the three experiments reported in this section support the expectation that increased visibility of targets would be associated with better performance when target aiding was in effect. What is uncertain is whether the prompting, as used in these initial studies, demonstrated any advantage lasting beyond the time aiding was available.

The most positive aspect possibly lies in the finding of a lack of significant difference during tests of the performance of prompted versus non-prompted subjects on the measures of target detection rate and mean time of search. This lack of a

statistically reliable advantage at test may obscure the evidence presented earlier (Experiments 8 and 9) concerning a statistically significant time of search advantage during training. Qualified by the fact that these initial studies used relatively few trials and subjects, the tentative finding of a training advantage in terms of time of search does signal a possible role for target enhancement.

However, findings restricted to the very initial stages of skill development should be cautiously interpreted. Schneider (1985), for example, cautioned against using performance in the early stages of high-performance skill training as a basis for predicting later performance in such training.

Given that further research is indicated, the following considerations should serve as guides in the development of more effective target modulation:

1. Effective prompting should obviously provide a means to expedite the extraction of target features and their encoding into associations, or links, between the actual target features and the detection response. Probably, target prompts should encode or embody the most invariant target features, perhaps in magnified form, to support the target detection process. These features can then be modulated on a trial-by-trial basis as learning progresses.

2. Most psychophysical functions are nonlinear in relation to the physical stimulus variations. The control of stimuli involved in prompting should perhaps take this into account. Adaptive control on a trial-by-trial basis should perhaps be adjustable and conform to a psychophysical function that could relate linear steps in perceived prompts to underlying nonlinearity in the physical prompt dimension.

3. Operators should not be storing features of the prompt, as opposed to the features of the actual target, in long-term memory. Ideally, prompts should embody the most invariant target features, which can then be faded over trials as learning progresses. As they fade, the ideal prompting features should point to the transformation of prompting features into non-prompted or actual target features. In this manner, the prompting features could be constantly predictive of true target features.

4. Pixel intensity prompting, although potentially effective in aiding target detection, may occlude essential target features by accentuating a pixel characteristic which is not a feature of actual targets. The essential target is not in the pixel appearance per se but rather, in the differential pattern of pixels over the displayed time and space of their occurrence. Therefore, a better target prompt would more closely correspond to, or cue, the spatial-temporal aspects of target occurrence. It is therefore recommended that a controllable mismatch in phase between target and noise pixels be installed and evaluated in its effectiveness in producing a usefully discernible cue. In this way, a slight mismatch in time of occurrence of target pixels, in relation to noise pixels, could be triply indicative of a target's time, location, and pattern of occurrence. Thus, it would probably be more suggestive of the main target feature (i.e., walking-dot pattern).

In summary, the following basic changes in the MXP system are suggested for consideration on the basis of the current results and observations: (a) installation of adaptive prompting in the MXP system; (b) evaluation of phasal prompting; (c) modification of the MXP system to permit stimulus alteration from trial to trial; (d) implementation of random switching of prompting/stimulus conditions to permit the use of randomization statistics and single-subject experimental designs; (e) introduction of capability for immediate presentation of a new target subsequent to each detection response; (f) provision of a

fully programmable nonlinear modulating function to control prompting dimensions; and (g) pursuit of further research with the existing target intensity feature under more prolonged training situations and with provisions for decrementing in a fully programmable way.

V. SUMMARY AND CONCLUSIONS

The results of the present training experiments indicate that performance levels which are consistent with automatic processing can be developed in tasks which involve spatial pattern information of the type required by operators of Air Force C2 systems. The results support the capability to develop automatic processing not only with static spatial pattern information, but with more complex dynamic pattern information as well. The static pattern work with non-categorized spatial pattern sets represents an important extension of earlier research by Eggemeier et al. (1990) that demonstrated evidence of automatic processing with categorized sets of static spatial pattern information. The demonstration of automatic processing performance characteristics with dynamic spatial pattern information is significant because it indicates that the processing of such information can be automatized and that the results of previous work that had not demonstrated reliable CM-VM differences do not reflect a general limit associated with the processing of such information.

The results of the final experiment in the training series did not produce reliable evidence of automatic processing in the CM condition in the complex rule-based alphanumeric task. As described earlier, this result may reflect the hybrid nature of the VM condition employed in the experiment. The latter condition included both consistent and inconsistent task elements, and demonstrated a substantial amount of improvement across training sessions. This improvement can be attributed to the consistency

present in the VM condition, and constituted one potential factor in the inability to demonstrate reliable CM-VM performance differences. It appears that the additional level of consistency present in the CM condition did not permit the demonstration of performance differences relative to the baseline provided by the hybrid VM condition.

The series of three experiments that examined the use of target prompting as an aid in the development of detection skills in the complex weather pattern search task demonstrated that visual prompting was effective in enhancing performance under the prompted conditions, but also showed that this advantage was not maintained when the prompting was withdrawn. It is important that the results did not demonstrate significant negative transfer to non-prompted test conditions. Results also suggested that prompting may represent a means of increasing the number of training trials per unit time. Such a capability would be of obvious practical significance to C2 training applications, and future work to address this issue and modified approaches to target prompting should be conducted.

The current research on transfer demonstrated some results that are suggestive of positive transfer to untrained exemplars of trained alphanumeric rules, but additional research will be required before firm conclusions concerning such transfer can be drawn. The need for further examination of the issue of transfer between lower and higher workload variants of complex tasks is also indicated by the present results, which did not demonstrate a differential effect on CM vs VM transfer performance in the complex weather pattern search task.

The results of the experiment that investigated the retention of spatial pattern information indicated that no significant decrements in the processing of such information occurred over a 30-day interval under the CM condition in the memory search task that was employed. This result is important in

that it extends the results obtained with previous semantic category information (Fisk et al., 1990) to an additional type of information processed by C2 operators, and indicates that automatic processing for such material can be maintained in memory search, over the time periods tested, without maintenance or refresher training.

Using the present results as a baseline, future research dealing with the acquisition of automatic processing should be extended to visual search paradigms. As discussed previously, visual search represents an important component of many C2 operator functions, and research with this type of paradigm is very important to C2 training applications. The recommended work should be conducted with both spatial pattern and complex alphanumeric information of the type researched here. In addition, work on the conditions and limits of transfer should be conducted with these types of information in a visual search paradigm. As discussed previously, training transfer with regard to spatial pattern and complex alphanumeric information is critical to many Air Force systems applications.

In addition to transfer, future work should examine the retention functions associated with dynamic spatial pattern information and complex alphanumeric information. It is important to extend this type of work to visual search paradigms as well, in that Fisk et al. (1990) have reported evidence that suggests that losses in performance under CM conditions over 30-day retention intervals are more pronounced in visual as opposed to memory search functions.

Such research is important to development of a refined methodology for structuring training programs that will support the acquisition of automatic processing in components of actual C2 operator tasks. The recommended extensions of the research reported here should contribute to eventual application of an

automatic-processing-based approach to high performance skills development in C2 operators.

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APPENDIX A: EXAMPLES OF SPATIAL PATTERN MATERIALS USED IN EXPERIMENTS 1 AND 7

Pattern	Target Movement Represented[1]
o o o o o	Constant Movement, Turn at Initiation
o o o o	Acceleration, No Turn
o o o o o	Deceleration, Turn at Completion

[1] The direction of pattern movement indicated in each case is from left to right.

APPENDIX B: EXAMPLE OF A RULE SET OF THE TYPE USED IN EXPERIMENT 4.

RULE	POSITIVE EXEMPLARS	NEGATIVE EXEMPLARS[2]
DXR 15 - 25	16 18 20 22 24	28 30 32 34 14
DXR 25 - 35	26 28 30 32 34	16 18 20 22 36
FLJ 28 - 38	30 32 34 36 28	18 20 22 24 40
FLJ 18 - 28	18 20 22 24 28	30 32 34 36 16
SKC 76 - 86	76 78 80 82 84	66 68 70 72 88
SKC 66 - 76	66 68 70 72 74	78 80 82 84 64
MTW 63 - 73	64 66 68 70 72	76 78 80 82 62
MTW 73 - 83	74 76 78 80 82	64 66 68 70 84

[2] In each case, the designated numerical exemplar would be presented with the three-letter acronym that appears under the "Rule" column in the same row as the exemplar.

• U. S. GOVERNMENT PRINTING OFFICE: 1991--761-052/40036